*Background Report* | September 2017

# Quantitative Assessment of Maritime Transport $CO_2$ and Fuel: Status Quo

Project „Deep Decarbonisation Pathways for Transport and Logistics Related to the Port of Rotterdam" (PoR Transport)

Deliverable Work Package 4

*Georg Kobiela*

on behalf of

Port of Rotterdam

Wuppertal Institut

This project has been commissioned by the Havenbedrijf Rotterdam Nv. The responsibility for the content rests solely with the authors and the opinions expressed are those of the individual authors.

Disclaimer: This report provides background information.
The overarching conclusions of the synthesis report are decisive.
Wuppertal Institute (2018): Deep Decarbonisation Pathways for Transport and Logistics related to the Port of Rotterdam. Synthesis Report. Authors: Stefan Lechtenböhmer, Dorothea Schostok, Georg Kobiela, Katharina Knoop, Andreas Pastowski, Simon Heck. On behalf of the Havenbedrijf Rotterdam Nv.
https://nbn-resolving.org/urn:nbn:de:bsz:wup4-opus-71405

**Project coordination:**
Wuppertal Institute for Climate, Environment and Energy
Dorothea Schostok, Katharina Knoop, Prof. Dr. Stefan Lechtenböhmer
Döppersberg 19
42103 Wuppertal
dorothea.schostok@wupperinst.org, katharina.knoop@wupperinst.org,
stefan.lechtenboehmer@wupperinst.org

**Author:**

Dr. Georg Kobiela

**Imprint**

**Editor:**
Wuppertal Institut für Klima, Umwelt, Energie gGmbH
Döppersberg 19
42103 Wuppertal
www.wupperinst.org

**Contact:**
Dr. Georg Kobiela
Division Future Energy and Mobility Structures
georg.kobiela@wupperinst.org
Tel. +49 202 2492-311
Fax +49 202 2492-108

**Status:** September 2017

# Table of Contents

# Collection of Abbreviations, Units and Symbols

## Abbreviations

| | |
|---|---|
| GDP | Gross domestic product |
| GHG | Greenhouse Gases |
| HFO | Heavy fuel oil |
| IMO | International Maritime Organization |
| LNG | Liquefied natural gas |
| MDO | Marine diesel oil |
| Roro / Ro-Ro | Roll on – roll off cargo |
| SI units | Measurement units according to the International System of Units, the modern metric system |
| TEU | Twenty-foot equivalent unit |
| WI | Wuppertal Institut für Klima Umwelt, Energie GmbH |
| W2T | Well-to-Tank |
| W2W | Well-to-Wheel |

## Units and Symbols

| | |
|---|---|
| DWT | Deadweight tonnage |
| g | Gram |
| kg | Kilogram |
| km | Kilometer |
| t | Ton (1000 kg) |
| kt | Kiloton (1000 t) |
| Mt | Megaton (1000.000 t) |
| Gt | Gigaton |
| tkm | Tonkilometer |
| GT | Gross tonnage |
| $CO_2$ | Carbon dioxide |
| $CO_2$-Eq. | Carbon dioxide equivalent |
| l | liter |

# List of Figures

# List of Tables

# 1 Introduction

The maritime part of all transport via the port of Rotterdam is linked to the brunt of all $CO_2$ emissions (87 %) the port can potentially influence. See the following diagram for a representation of emission shares of different modes of transport.

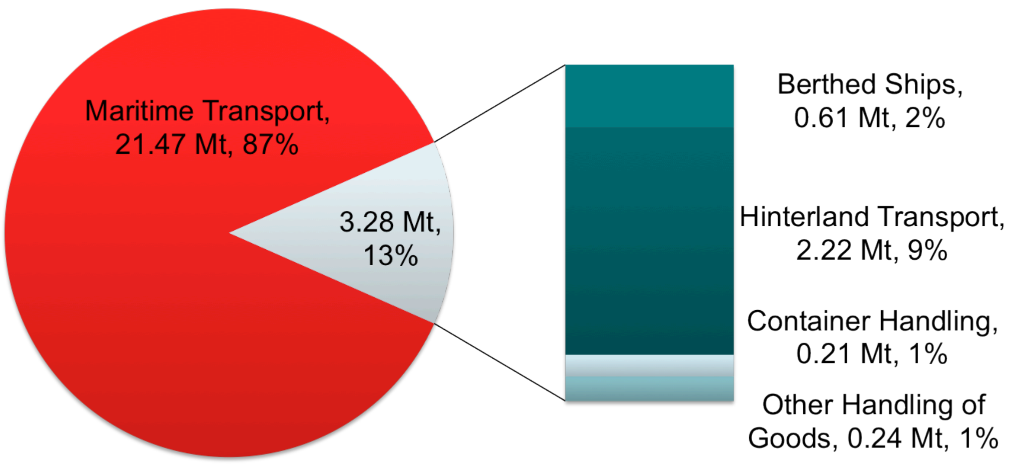



**Figure 1-1 Transport related $CO_2$ emissions related to the Port of Rotterdam, own assessment**

This report aims to quantitatively grasp the maritime transport of the Port of Rotterdam, in terms of ships, total tonnages, energy consumption and $CO_2$ emissions in respect to types of cargo and regions.

In the first and broad part of the report, the emissions and energy demands of sailing ships are assessed. Emissions and energy demand for the port itself are subject of a separate part at the end.

Various studies focus on the global maritime sector. The International Maritime Organization (IMO) finds a clear correlation between maritime bunker fuels and gross domestic product (GDP), with both showing a visible trough from the 2009 recession (IMO 2015). At the same time, GHG (greenhouse gas) emissions went down, mainly (but not solely) caused by a change of fuel type, from HFO (heavy fuel oil) to a larger proportion of MDO (maritime diesel oil) and LNG (liquefied natural gas) - The IMO finds a significantly higher ratio of MDO usage compared to HFO in domestic navigation, while international shipping remains largely HFO-based. Therefore, the $CO_2$ intensity of energy throughput by international shipping is higher than the $CO_2$ intensity by domestic navigation. For further details, see Figure 5-5 in the Appendix.

This change in fuel quality towards fuels with a higher exergy density (unit of useful work per unit of mass) still yields further potential, but will eventually meet a limit. For a further reduction, more substantial strategies will need to be developed.

Depending on the method of analysis, the IMO finds somewhat contradicting trends for $CO_2$ emissions of global maritime transport – while their top-down approach via aggregate figures of fuel usage displays a slight increase in emissions, their bottom-up approach shows a slight decline.

However, the $CO_2$ emission share of the maritime sector (mainly but not solely caused by international shipping), which accounts for about 3 % of global $CO_2$ emissions from the combustion of carbon fuel, is declining, as shown in Table 1-1. This is mainly due to the rise of global emissions in the considered period 2007-2012 (IMO 2015).

**Table 1-1 Global maritime $CO_2$ emissions 2007-2012 in Mt, assessed by two different IMO methods (Data: IMO 2015)**

| Marine sector | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | Average |
|---|---|---|---|---|---|---|---|
| Top-down international total | 625.5 | 624.0 | 596.4 | 647.5 | 648.9 | - | - |
| Top-down domestic total | 134.9 | 121.0 | 123.4 | 127.1 | 127.6 | - | - |
| Top-down fishing total | 20.8 | 19.2 | 19.3 | 19.2 | 19.0 | - | - |
| **Total $CO_2$ emissions, top-down** | **781.2** | **764.1** | **739.1** | **793.8** | **795.4** | **-** | **775** |
| Bottom-up international total | 884.9 | 920.9 | 855.1 | 771.4 | 849.5 | 795.7 | - |
| Bottom-up domestic total | 196.5 | 196.2 | 112.6 | 133.3 | 159.7 | 131.4 | - |
| Bottom-up fishing total | 18.6 | 18.0 | 10.2 | 10.0 | 12.3 | 11.0 | - |
| **Total $CO_2$ emissions, bottom-up** | **1100.1** | **1135.1** | **977.9** | **914.7** | **1021.6** | **938.1** | **1015** |
| **Share of global fossil-fuel $CO_2$ emissions** | **3.5 %** | **3.5 %** | **3.1 %** | **2.7 %** | **2.9 %** | **2.6 %** | **3.1 %** |

For the Port of Rotterdam, the assessment of maritime $CO_2$ emissions yields multiple interesting aspects: How big are the emissions directly caused by goods transferred via the port and how can these be divided into subcategories? How big are the overall emissions the port's policies and regulations might have influence upon? It is precisely this second aspect, the potentially influential and therefore potentially reducible emissions, that should be of interest from the perspective of climate change. In the following, two different methods of assessment are presented and applied. In their introduction, the difference between an emission allocation by cause and an allocation by reduction potential becomes more apparent.

# 2 Methodology

For assessing the total $CO_2$ emissions, two methods have been applied, which in some respects yield substantially different results. In the first approach, the list of all ships passing through Rotterdam was used, with specifications for each ship about its type-specific size. Though it was not possible to find data about the amount of freight each ship was loading or unloading, the deadweight tonnage (DWT) of these ships was possible to be used. This is valid under the assumption that all ships were full, both when arriving and when leaving. In the second approach, data about the freight and its origin or, respectively, its destination, was used. This was done without consideration of the specific ship, its type and size.

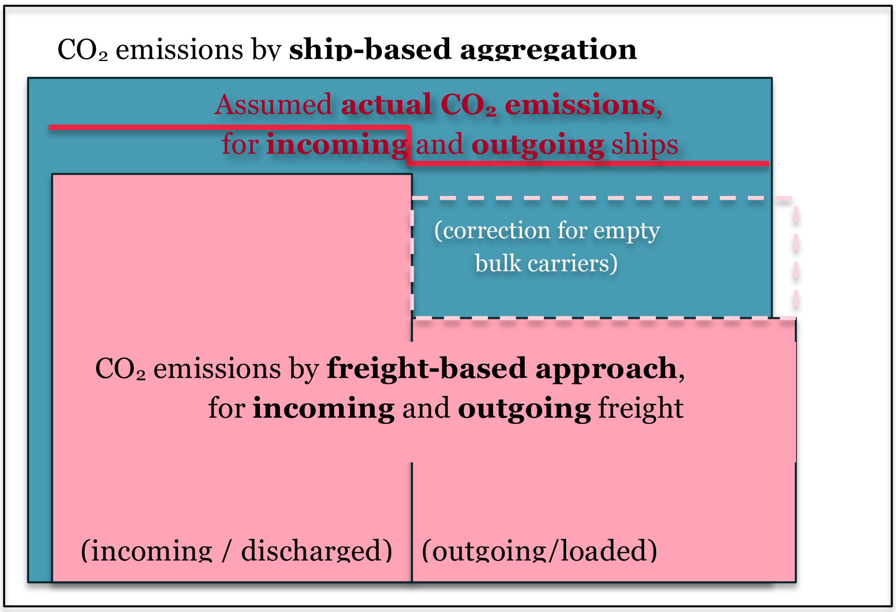



**Figure 2-1 Schematic representation of the applied methods for $CO_2$ emissions in relation to actual emissions**

A schematic comparison between the two approaches is shown in Figure 2-1. While the first approach systematically overestimates the total freight, it draws an accurate picture of the shipping capacity and takes all ship travel into account, even the empty ships that arrive and, more frequently, those that leave Rotterdam after complete unloading. As the energy demand and $CO_2$ emissions of these empty or largely unloaded ships are still significant, and as they are by and large in the same order of magnitude as fully loaded ships, an essential part of emissions is covered in the ship-based approach. In contrast, the freight-centered approach can not take this into account without further adjustment. Also, when a ship is only partially (un)loaded in Rotterdam, which is common practice for container vessels, the part of cargo that stays on-board is included in the statistic. With this consideration, the derived figures for the ship-based approach can be regarded as an upper limit of the overall maritime $CO_2$ emissions the Port of Rotterdam is directly causing by cargo processing. They are a sound estimate of maritime $CO_2$ emissions that the port of Rotterdam can influence (even if they can not be directly attributed to Rotterdam), but are yet probably also slightly too high. For utilization factors of various types of ships, see Table 5-1.

For the bottom-up ship aggregation approach, the Port of Rotterdam provided data for all incoming and outgoing maritime vessels in 2015 (28 891 entries), including their GT (gross tonnage), DWT (deadweight tonnage), length, previous and next port, covering some 2 000 different destinations. Also included were the type of shipment (“BULK”, “COMBI”, “DREDGING”, “FISHING”, “GEN CARGO”, “LNG”, “NAVY”, “OFFSHORE”, “OTHER”, “PASSENGER”, “PONTOON”, “SAIL”, “SALVAGE”, “TANKER”, “TUG”, UNKNOWN”, “WORKSHIP”, “YACHT“) and further cargo subcategory specifications. The cargo specification (“BREAKBULK”, “CASCO”, “CONTAINERIZED”, “EMPTY”, “ENVIRONMENTAL_POLLUTANT_CARGO”, “FROZEN_CARGO”, “HAZARDOUS_CARGO”, “LIQUID_CARGO”, “NOT_HAZARDOUS_CARGO”, “OTHER_NON_CONTAINERIZED”, “OUT_OF_GAUGE”, “PALLETIZED”, “ROLL_ON_ROLL_OFF”, “TEMPERATURE_CONTROLLED_CARGO”, “VEHICLES”) appears partly unclear and has not been further analyzed as it was not specified between the incoming and outgoing freight, which proved to be especially problematic for the entry “EMPTY”, as this was probably just an empty arrival or departure, most likely not both. As not all data sets are complete (for instance, some are lacking the DWT, some the ship category or subcategory data), strategies had to be found to circumvent distortions and to make optimal use of these entries.

The ports were listed by name and not by International Port Code. This made the identification process more complex and lead to possible errors. The ports were identified and distances derived via online maritime route calculators (AIS Marine Traffic 2017; Davis 2016) and Google Maps. Ambiguous ports: Where several ports exist with the same name these were identified by checking with the shipment type and with the other corresponding port (either port of origin or of destination) along the same shipment route in the data. From the multiple entries of this port name, the one with the highest seeming plausibility in combination with the corresponding port was picked. Example: “BRISTOL” was identified as the Port of Bristol, UK and not the Port of Bristol Bay, USA, by comparing it with the connected ports in the shipment data (all European) and the type of shipment (generally “BULK” and also “ROLL_ON_ROLL_OFF”), which is almost entirely subject to the European short sea shipping. In this, it was assumed that there are no two actual ports assigned to the same port name in the data. The derived data in nautical miles was then converted to km, as all further considerations were done within SI-units. 99.64% of all port entries were successfully identified. For the remaining entries, a compensating emission factor was applied, following the assumption that the shipment entries have the same coverage ratio. Therefore, on all total aggregate values, a correction factor of 1.0036 was multiplied.

For the specific $CO_2$ emissions in g/tkm and for energy usage, IMO data was used. The data for ship categories from IMO specifies between various types (“Chemical tanker”, “Container”, “General cargo”, “Refrigerated bulk”, “Bulk carrier”, “Service – tug”, “Chemical tanker”, “Ro-ro”, “Liquefied gas tanker”, “Oil tanker”, “Other liquids tankers”, “Ferry – ro-pax”, “Miscellaneous – other”, “Service – other”, “Vehicle”, “Cruise”, “Yacht”, “Offshore”, “Miscellaneous – fishing”) and multiple respective size classes (IMO 2015). For the entire list of IMO ship categories and sizes, see Figure 5-1 to Figure 5-3.

Where available, the ship subcategories of Rotterdam data were used to map the listed shipments to IMO ship categories. Where the subcategories were not available, the coarser ship categories were used. Depending on the IMO ship category, either the GT or DWT of the Rotterdam data were used to map the shipments to the IMO ship sizes of the individual IMO ship categories. For container ships and vehicle transporters, the IMO size classifications first had to be converted to DWT. For this purpose, the number of TEUs (Twenty-foot equivalent unit, aka one standard container) was matched to mass by assuming a standard weight of 12 t per container, assembled by 10 t of freight plus 2 t for the container itself (den Boer et al. 2017)[1]. The average mass the vehicles was assumed to be 1.39 t (ICCT 2016)[2]. No standardized and generally applicable conversion scale from tank volume to DWT was found for LNG tankers, so that an average emission intensity value was used for all ship sizes.

For shipments on inland routes and for pontoon shipments, emission intensity values were used for inland vessels, which are divided into three classes by length (den Boer et al. 2017). For more details, see Figure 5-4 in the Appendix. Assuming that these ships will generally use MDO as fuel, these energy demands are translated into fuel usage and $CO_2$ emission intensities, with 2.66 kg $CO_2$/l. Only the emissions from tank-to-wheel (T2W) are taken into consideration, but not the full well-to-wheel (W2W) emissions (Schmied und Knörr 2013). All energy demands refer to the final energy, not to the primary energy demands. If these were included, the total energy demand would increase substantially.

Based on the IMO data, the fuel consumption and $CO_2$ emissions behave proportional to each other, with slight differences between the individual types of ships; to get a relatively good estimate of total fuel consumption even when only emission data is available, a factor of 3 is reasonable (3 t $CO_2$ per t of fuel) and yields data in line with the overall precision of this assessment (the average emission intensity of all ship types is 3.26 $t_{CO2}/t_{fuel}$, the median is 3.02 $t_{CO2}/t_{fuel}$).

It proved unfeasible to distinguish between feeder transport and other modes of short sea shipping based on the data. Therefore, only two modes were used for differentiation: European short sea shipping and deep sea shipping. This distinction is done according to the classification used by Eurostat – which basically includes all continental European countries, the United Kingdom and Ireland as well as all the Baltic, Mediterranean and Black Sea countries (Eurostat 2017). For the detailed list, see Table 5-2 in the Appendix. However, most deep sea shipping vessels pass through more than one European port on their journey. In order to distinguish between these deep sea shipping passages and normal short sea shipping, both the port of origin and the port of destination have been considered. In the unambiguous cases where both routes belong to the European short sea shipping area, this mode has been assigned to overall shipment. In cases where at least one route transcends this short sea shipping area, the entire shipment has been assigned to deep sea shipping.

A further differentiation has been made to evaluate the number, DWT, tkm, $CO_2$ emissions, and emission intensity for the different types of shipment in respect to the

[1] "Voor 1 TEU (20 ft container) is een gemiddeld ladinggewicht van 10 ton genomen en een gemiddeld containergewicht van 2 ton. Voor de 40 ft en 45 ft containers is dit gewicht lineair opgeschaald." (den Boer et al. 2017)

[2] "The average mass of new cars in the EU remained about constant, at 1 390 kg in 2014. Ten years earlier, the average weight was around 1 330 kg. As in previous years, both the German and Swedish new car fleets were significantly above the EU average, at 1 474 and 1 574 kg respectively. In contrast, French, Italian and Dutch consumers opted for significantly lighter cars (1 303, 1 319, and 1 299 kg respectively)." (ICCT 2016)

modes (total, deep sea and short sea shipping) as well as to countries, regions and larger continental regions.

These derived emission intensities for shipments to different regions were then fed into the aggregated freight approach, which starts with an inventory, supplied by the Port of Rotterdam, about all goods discharged or loaded form and onto maritime vessels in 2015, with their assigned origins or final port destinations. For Central Asia, there was no emission intensity available from the shipment-based approach, as no Central Asian destination was reached directly from Rotterdam. Therefore, the value for Eastern Europe and Northern Asia (4.40 g/tkm each) was used. Entries of goods with unknown origin or destination (13.59 Mt cargo, about 3.0 % of the total) and other incorrect entries are not included in the emission statistics, but are added to the total values as a correction factor of 1.041. This approach yields the advantage of being able to actually track the goods all the way to their final destination, irrespective of other ports that the ship could enter along its route, and more accurately represents the actual amount of goods changing their devices of transport in Rotterdam. However, it is blind to the size of the actual ships and the potential resulting inefficiencies of empty or only partially loaded ships and works with the assumption of perfect ship sizes for the transported goods. Thus, while in the first approach, the amount of goods has been adjusted to the ships’ capacities, the second approach adapts the ship's sizes and capacities to the transferred cargo.

# 3 Findings

For the aggregated total $CO_2$ emissions, the two approaches yield substantially different results, as shown in Table 3-1 and further explained in Figure 3-1.

**Table 3-1 Key results of both assessment methods**

| | Bottom-up via ship data | Aggregate freight data approach, unadjusted |
|---|---|---|
| Total $CO_2$, in Mt | 21.47 | 14.37 |
| Total DWT in Mt | 1627.3 | 471.6 |
| Aggregate tkm | 4.62*10^12 | 3.35*10^12 |
| $CO_2$ Emission intensity in g/tkm | 4.90 | 4.97 |

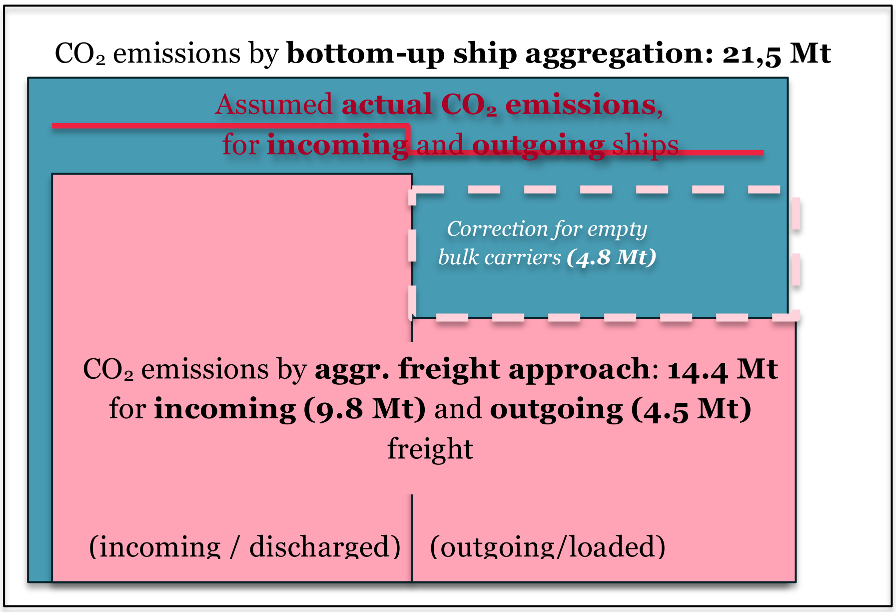



**Figure 3-1 Schematic results for total $CO_2$ emission assessment via both methods**

While the aggregate tkm value lies in the same order of magnitude for both, the total freight (for the ships, the DWT is used) differs strongly, almost by a factor of 4. The total weight of freight is relatively well in line with the values reported by Eurostat for Rotterdam (436.9 Mt in 2015; see also Table 3-10).

This shows the difference in methods, but also shows that only about one forth of the shipment capacity is included in the aggregated freight assessment assessment– regardless of whether these are actually used (as in the case of container ships some of the other transports that might only be partially unloaded or reloaded in Rotterdam) or whether they are empty transports (as is the case for bulk freighters in particular, which are often only unloaded but not reloaded in Rotterdam). This is also mirrored in the capacity utilization of other studies, see Table 5-1. Due to the large share of empty shipments, bulk carriers are only utilizing roughly half their tkm-capacity.

It would also be erroneous to assume that only the (smaller) $CO_2$ emissions of the aggregate freight approach would be caused by the Port's transfer of goods – since these are empty shipments, which are inherently part of the overall ship's movements and are unavoidable if there is no balance between incoming and outgoing bulk transport. With an additional correction for bulk transporters, which is explained in more detail at the end of chapter 3.2.1 (page 31ff.), empty travels of bulk carriers are included in the aggregate freight approach. This increases the total emissions to 19.1

Mt, or 89 % of the value of the ship's approach. If the same assumptions also apply to all types of freight, the value rises to 20.0 Mt or 93 % of the ship approach.

With a different adjustment method using ship type-specific capacity utilization factors (see Table 5-1 and Table 3-9) the $CO_2$ emission values of the aggregated freight approach increase by 168 % to 24.2 Mt, or 112 % of those estimated by the ship approach. However, this seems to lead to a certain double discounting, as some efficiency lacks should already be included in the empirical IMO fuel and emission intensities on which this assessment is based.

If not noted otherwise, the results refer to the first approach, the assessment by shipment aggregation.

The whole assessment is mainly based on $CO_2$ emissions. As briefly discussed in the previous chapter, however, an estimation of the fuel consumption can be derived from this by using an emission intensity value of 3 $t_{CO2}/t_{fuel}$. This corresponds to the value of 3.08 $t_{CO2}/t_{fuel}$ used by the Ecoinvent Centre (Ecoinvent 2012b). This yields to a total fuel consumption of 7.1 Mt of fuel (mainly HFO) for the bottom-up ship approach, and 6.4 Mt of fuel (also mainly HFO) for the aggregate freight approach.

## 3.1 Regional differentiation

The total average of $CO_2$ emission intensity is estimated at 4.90 g/tkm, an overview over the different aggregate regions is given in Table 3-2 and Table 3-3 and is visualized in

Figure 3-3.

**Table 3-2 Aggregate travel data by regions, part 1**

| | Northern Africa | Southern Africa | Western Africa | Eastern Africa | Central Africa | Central Atlantic | South Atlantic | Indian Ocean | Southeast Asia | East Asia | Southern Asia | Southern Pacific | Oceania | Western Asia | Northern Asia |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Total $CO_2$ in Mt** | 2.050 | 0.976 | 0.416 | 0.004 | 0.201 | 0.004 | 0.001 | 0.014 | 1.930 | 2.220 | 0.193 | 0.001 | 0.262 | 0.772 | 0.989 |
| **% of total $CO_2$ emission** | 9.55 | 4.55 | 1.94 | 0.02 | 0.94 | 0.02 | 0.003 | 0.06 | 8.99 | 10.34 | 0.90 | 0.006 | 1.22 | 3.60 | 4.61 |
| **Average $CO_2$ per shipment in t** | 2 002 | 8 339 | 1 731 | 1 202 | 4 375 | 557 | 679 | 3 458 | 6 308 | 12 200 | 3 855 | 1 367 | 4 444 | 2 070 | 600 |
| **Number of shipments** | 1 024 | 117 | 240 | 3 | 46 | 7 | 1 | 4 | 306 | 182 | 50 | 1 | 59 | 373 | 1 647 |
| **Average distance of shipments in km** | 5 103 | 11 664 | 7 092 | 9 591 | 8 574 | 4 867 | 7 367 | 14 591 | 16 011 | 20 364 | 13 308 | 17 333 | 21 303 | 8 215 | 3 152 |
| **Total DWT in Mt** | 102.5 | 11.3 | 23.3 | 0.03 | 4.52 | 0.18 | 0.01 | 0.49 | 44.9 | 16.9 | 4.35 | 0.01 | 6.09 | 23.4 | 88.2 |
| **Av. DWT in kt** | 100.0 | 94.0 | 96.4 | 10.7 | 88.6 | 26.0 | 7.1 | 122.0 | 144.4 | 92.3 | 87.1 | 11.8 | 101.5 | 62.9 | 53.6 |
| **$CO_2$ emission intensity in g/(t km)** | 3.93 | 7.61 | 2.53 | 11.68 | 5.76 | 4.41 | 13.08 | 1.94 | 2.73 | 6.49 | 3.33 | 6.71 | 2.06 | 4.01 | 3.55 |

**Table 3-3 Aggregate travel data by regions, part 2**

| | Southeastern Europe | Southwestern Europe | Central Europe | Eastern Europe | Northern Europe | Southcentral Europe | North America West | North America East | South America East | South America West |
|---|---|---|---|---|---|---|---|---|---|---|
| Total $CO_2$ in Mt | 0.317 | 1.410 | 0.790 | 0.269 | 1.140 | 0.185 | 1.699 | 1.124 | 1.328 | 0.329 |
| % of total emission | 1.48 | 6.57 | 3.68 | 1.25 | 5.31 | 0.86 | 7.91 | 5.23 | 6.19 | 1.53 |
| Average $CO_2$ per shipment in t | 1 384 | 466 | 135 | 268 | 221 | 703 | 2 480 | 1 650 | 3 503 | 1 898 |
| Number of shipments | 229 | 3 021 | 5 816 | 1 002 | 5 159 | 263 | 685 | 681 | 379 | 173 |
| Average distance of shipments in km | 5 542 | 2 329 | 568 | 2 227 | 1 663 | 5 341 | 8 532 | 8 189 | 10 700 | 8 738 |
| Total DWT in Mt | 13.6 | 90.5 | 246.4 | 27.3 | 106.7 | 5.90 | 38.3 | 39.6 | 39,0 | 18.5 |
| Av. DWT in kt | 58.9 | 29.9 | 42.3 | 27.3 | 20.6 | 22.2 | 56.0 | 58.1 | 102.0 | 106.7 |
| $CO_2$ emission intensity in g/(t km) | 4.24 | 6.71 | 5.66 | 4.42 | 6.46 | 5.92 | 5.19 | 3.47 | 3.21 | 2.04 |

While the high emission intensities for the Atlantic destinations and for Eastern Africa should not be considered as strongly corroborated due to their low statistical base (only very few individual shipments), the high emission intensities for Southern Africa and for many European destinations become apparent. Overall, short sea shipping, especially for the short routes in Western, Northern and Southern Europe causes higher emission intensities as longer distances, which might partly be due to the higher efficiency pressure on longer total distances.

**Table 3-4 Regional differentiation for aggregate freight approach, part 1**

| Larger continental regions | Aggregate freight in Mt | Share of total freight | Average country distance in km | aggregate 10^9 tkm | Share of total tkm | $CO_2$ intensity in g/tkm | $CO_2$ emissions in Mt | Share of total $CO_2$ emissions |
|---|---|---|---|---|---|---|---|---|
| Africa & adj. Oceans | 59.9 | 13.2 % | | 479.8 | 14.3 % | | 2.35 | 16.4 % |
| Asia | 148.3 | 32.7 % | 13 050 | 1 726.4 | 51.5 % | 3.92 | 7.86 | 54.7 % |
| South and East Asia & Oceania | 78.9 | 17.4 % | | 1 406.4 | 41.9 % | | 6.25 | 43.5 % |
| North and Western Asia | 75.7 | 16.7 % | | 457.1 | 13.6 % | | 1.89 | 13.2 % |
| Europe | 147.7 | 32.6 % | 2 976 | 215.5 | 6.4 % | 5.69 | 1.36 | 9.4 % |
| Western Europe | 60.5 | 13.4 % | 1 370 | 48.3 | 1.4 % | 7.70 | 0.37 | 2.6 % |
| Europe without West | 87.2 | 19.2 % | | 167.1 | 5.0 % | | 0.98 | 6.8 % |
| North America | 42.7 | 9.4 % | 8 495 | 339.4 | 10.1 % | 3.77 | 1.27 | 8.8 % |
| South America | 48.0 | 10.6 % | 10 183 | 454.7 | 13.6 % | 2.48 | 1.24 | 8.6 % |
| **Total** | **453.0** | **100 %** | **8 824** | **3 352.9** | **100 %** | **4.99** | **14.37** | **100 %** |

**Table 3-5 Regional differentiation for aggregate freight approach, part 2**

| Regions | Aggregate freight in Mt | Share of total freight | Average country distance in km | aggregate 10^9 tkm | Share of total tkm | $CO_2$ intensity in g/tkm | $CO_2$ emissions in Mt | Share of total $CO_2$ emissions |
|---|---|---|---|---|---|---|---|---|
| North Africa | 22.28 | 4.9% | 4 592 | 128.4 | 3.8% | 3.89 | 0.50 | 3.5% |
| East Africa | 1.21 | 0.3% | 14 170 | 17.4 | 0.5% | 11.68 | 0.20 | 1.4% |
| Central Africa | 6.40 | 1.4% | 9 211 | 56.9 | 1.7% | 5.76 | 0.33 | 2.3% |
| West Africa | 18.90 | 4.2% | 6 458 | 138.6 | 4.1% | 2.53 | 0.35 | 2.4% |
| Southern Africa | 9.99 | 2.2% | 11 460 | 123.4 | 3.7% | 7.61 | 0.94 | 6.5% |
| Central Atlantic | 0.26 | 0.1% | 5 434 | 1.3 | 0.0% | 4.41 | 0.01 | 0.0% |
| Indian Ocean | 0.85 | 0.2% | 15 444 | 13.8 | 0.4% | 1.94 | 0.03 | 0.2% |
| South Asia | 4.26 | 0.9% | 12 926 | 54.7 | 1.6% | 3.33 | 0.18 | 1.3% |
| Southeast Asia | 33.91 | 7.5% | 16 495 | 541.2 | 16.1% | 2.73 | 1.48 | 10.3% |
| East Asia | 33.53 | 7.4% | 19 851 | 659.9 | 19.7% | 6.49 | 4.28 | 29.8% |
| South Pacific | 0.03 | 0.0% | 18 608 | 0.5 | 0.0% | 6.71 | 0.00 | 0.0% |
| Oceania | 7.20 | 1.6% | 19 794 | 150.0 | 4.5% | 2.06 | 0.31 | 2.1% |
| Western Asia | 23.38 | 5.2% | 9 371 | 253.8 | 7.6% | 3.95 | 1.00 | 7.0% |
| Central Asia | 0.21 | 0.0% | 6 982 | 1.5 | 0.0% | 3.30 | 0.00 | 0.0% |
| Northern Asia | 52.16 | 11.5% | 3 870 | 201.9 | 6.0% | 4.40 | 0.89 | 6.2% |
| Central Europe | 10.36 | 2.3% | 816 | 6.3 | 0.2% | 5.65 | 0.04 | 0.2% |
| Eastern Europe | 9.80 | 2.2% | 3 562 | 36.8 | 1.1% | 4.40 | 0.16 | 1.1% |
| Western Europe | 60.53 | 13.4% | 1 370 | 48.3 | 1.4% | 7.70 | 0.37 | 2.6% |
| Northern Europe | 53.22 | 11.8% | 2 203 | 81.6 | 2.4% | 6.45 | 0.53 | 3.7% |
| Southwestern Europe | 10.58 | 2.3% | 2 449 | 26.2 | 0.8% | 6.70 | 0.18 | 1.2% |
| Southcentral Europe | 1.77 | 0.4% | 5 296 | 8.5 | 0.3% | 5.88 | 0.05 | 0.3% |
| Southeastern Europe | 1.45 | 0.3% | 5 534 | 7.8 | 0.2% | 4.31 | 0.03 | 0.2% |
| North America West | 3.45 | 0.8% | 11 790 | 44.1 | 1.3% | 5.19 | 0.23 | 1.6% |
| North America East | 38.75 | 8.6% | 8 038 | 291.2 | 8.7% | 3.53 | 1.03 | 7.2% |
| South America West | 18.69 | 4.1% | 10 798 | 183.9 | 5.5% | 2.04 | 0.37 | 2.6% |
| South America East | 29.78 | 6.6% | 9 038 | 274.9 | 8.2% | 3.20 | 0.88 | 6.1% |

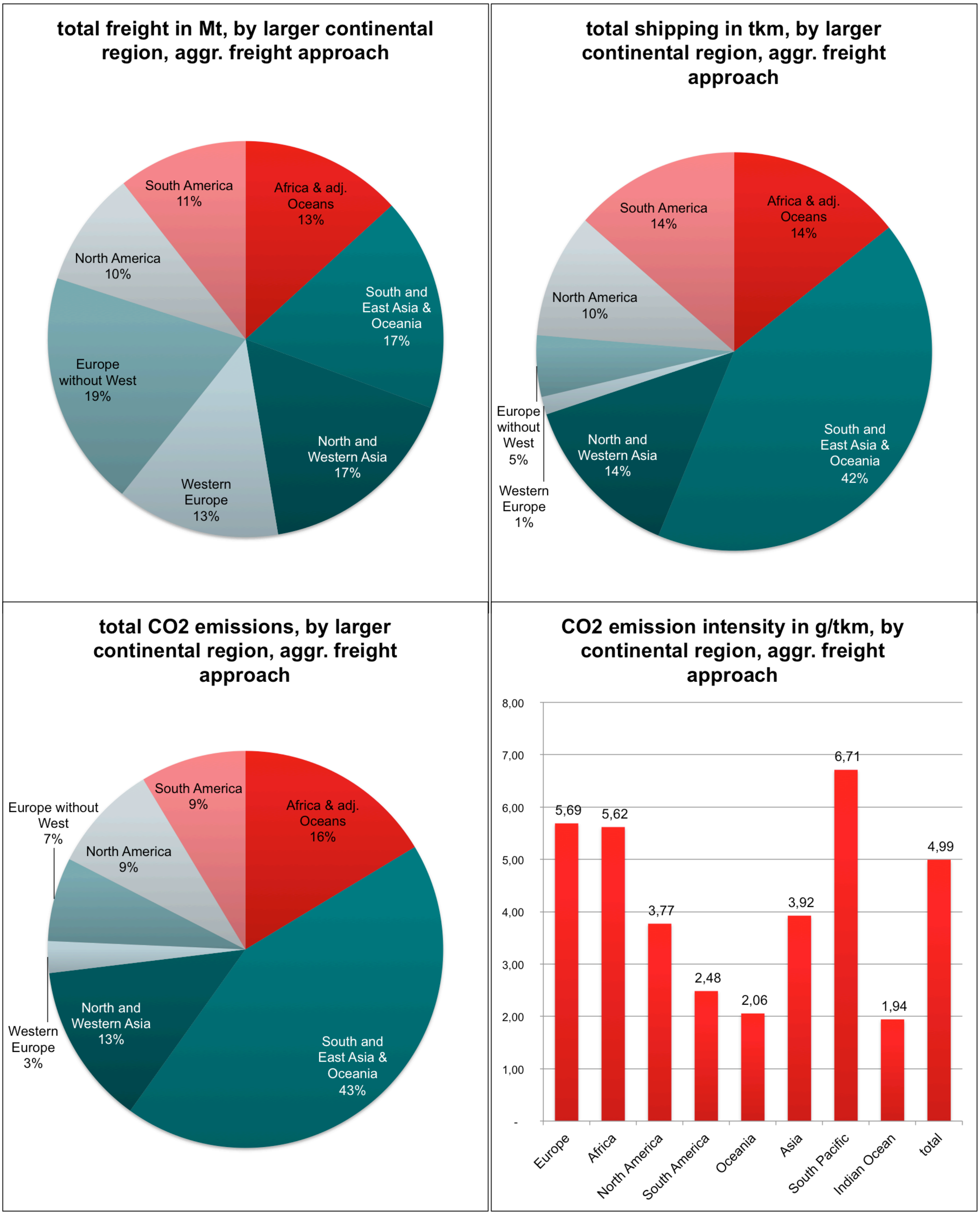



**Figure 3-2 Relative aggregate freight, tkm and $CO_2$ emissions by larger continental region via the aggregate freight approach; the $CO_2$ emission intensities are presented for a different regional set**

Table 3-4, 3-5 and Figure 3-2 show freight tonnage, tkm, $CO_2$ emissions and emission intensities with regional differentiation derived via the aggregate freight approach. As illustrated in the top left graph of Figure 3-2, the freight tonnage is rather evenly distributed between Europe, Asia, and as a third part South America and Africa with the adjacent Oceans. Due to the shorter distances, the emissions per unit of freight are substantially lower in Europe than for the other regions. Asia and there most significantly East Asia carry the largest share of total tkm and $CO_2$ emissions. 71 000%

Especially South and East Asia, and Western Europe appear very different when both approaches are compared – while the aggregate freight approach shows small shares in respect to tkm and $CO_2$ emissions, the shipment aggregation suggests large shares for Western Europe (see Figure 3-9 to Figure 3-11). In this, there is a likely distortion that part of the (containerized) deep sea shipping to destinations like East Asia is assigned to European short sea shipping, when both before and after the Port of Rotterdam other European ports are passed by the freighter.

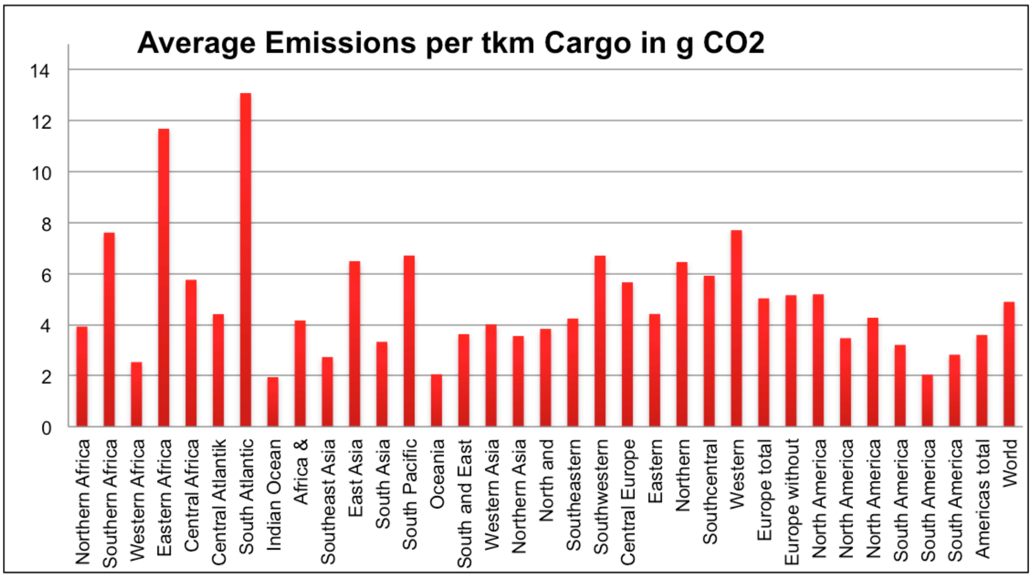



**Figure 3-3 Average $CO_2$ emission intensities in g per tkm by region**

In Table 3-6, the previously presented regions analyzed with the shipment aggregation method are aggregated to larger continental regions.

**Table 3-6 Aggregate travel data by larger regions/continents**

| | Africa & adj. Oceans | South and East Asia & Oceania | North and Western Asia | Asia total | Western Europe | Europe without West | Europe total | North America | South America | America total | World total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Total $CO_2$ in Mt** | **3.67** | 4.61 | 1.76 | **6.37** | 2.84 | 4.11 | **6.95** | 2.82 | 1.66 | **4.48** | **21.47** |
| **% of total $CO_2$ emission** | **17.07** | 21.46 | 8.20 | **29.66** | 13.24 | 19.15 | **32.40** | 13.15 | 7.72 | **20.87** | **100** |
| **Av. $CO_2$ per shipment in t** | **2577** | 7769 | 876 | **2448** | 130 | 297 | **249** | 2097 | 3056 | **2429** | **746** |
| **Number of shipments** | **1422** | 593 | 2008 | **2601** | 21780 | 13827 | **27917** | 1346 | 542 | **1844** | **28789** |
| **Av. distance of shipments in km** | **6228** | 17775 | 4111 | **7259** | 548 | 1631 | **1189** | 8485 | 10273 | **9214** | **2702** |
| **Total DWT in Mt** | **142.3** | 72.3 | 111.6 | **183.9** | 675.3 | 490.4 | **1165.7** | 77.9 | 57.4 | **135.4** | **1627.3** |
| **Av. DWT in kt** | **99.4** | 120.4 | 55.6 | **70.5** | 30.9 | 35.4 | **41.6** | 57.9 | 105.4 | **73.3** | **56.3** |
| **$CO_2$ emission intensity in g/tkm** | **4.16** | 3.63 | 3.84 | **4.78** | 7.70 | 5.16 | **5.03** | 4.27 | 2.82 | **3.60** | **4.90** |

The Western European region in particular shows a specifically high emission intensity. At the same time, this region also yields the highest aggregate DWT, while the average DWT of individual shipments is the lowest. Especially the furthest regions with the high average distances of Africa, South and East Asia and South America show very high average ship sizes in terms of DWT and low emission intensities. However, these regions also yield the highest average $CO_2$ emissions per shipment. In terms of total $CO_2$ emissions, Europe has the largest share of the worldwide shipments to and from Rotterdam, accounting for around one third of total CO2 emissions.

In Figure 3-4 to Figure 3-11 further aspects are graphically represented. To assess the statistical deviation, standard deviations were calculated for both the DWT and the $CO_2$ emissions. Figure 3-5 includes the standard deviation for individual trips in terms of $CO_2$ emissions. In Figure 3-6, the deviation in terms of emission intensity $i = e/(d*t)$ was calculated as
$\Delta i = | 1/(d*t) | * \Delta e + | e/(d*t^2) | * \Delta t$
with the emission intensity $i$, average emissions $e$, average distance $d$, average deadweight tonnage $t$. These values should not be read as uncertainties in the data, but rather as a display of the large deviations between the individual shipments.

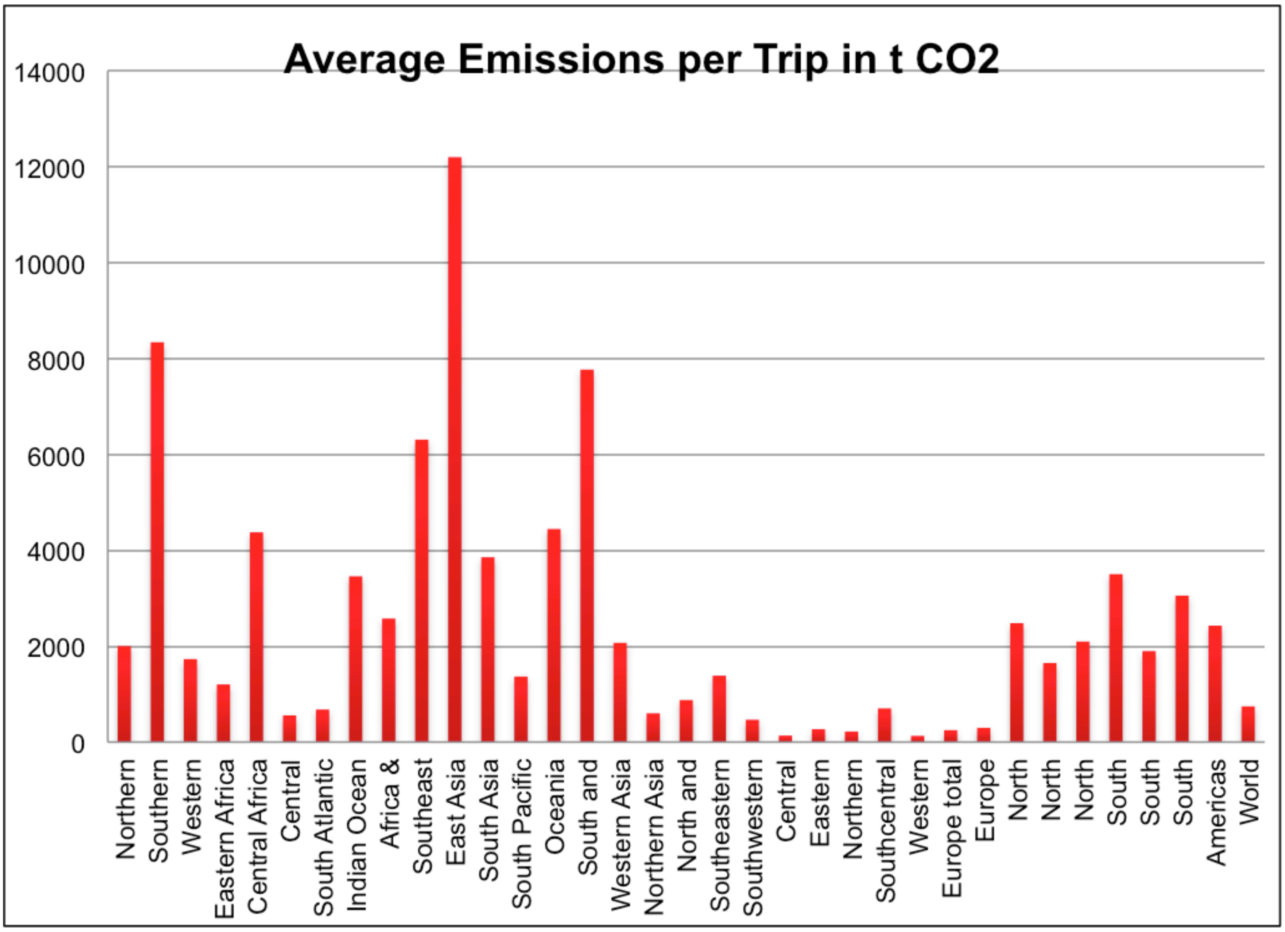



Figure 3-4 Average $CO_2$ emissions in t per individual trip

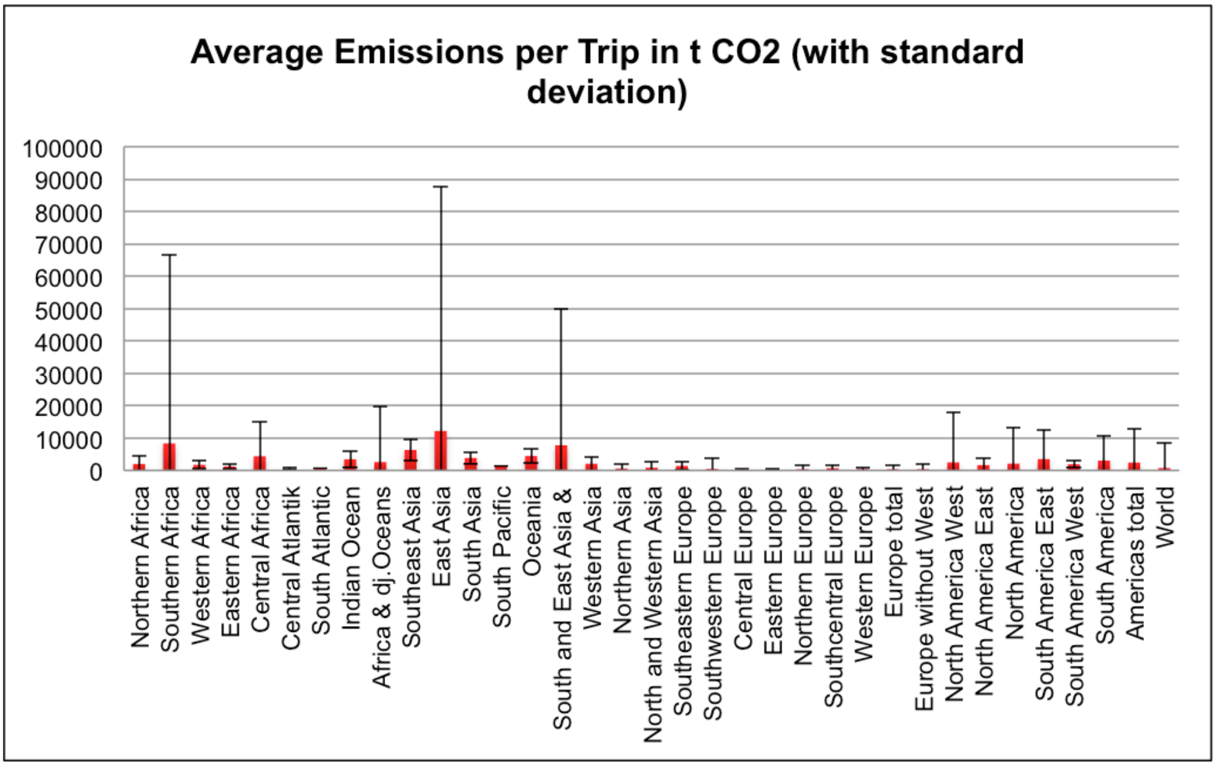



**Figure 3-5 Average $CO_2$ emissions per individual trip (with standard deviation)**

The total average of $CO_2$ emission per trip is 748 t.

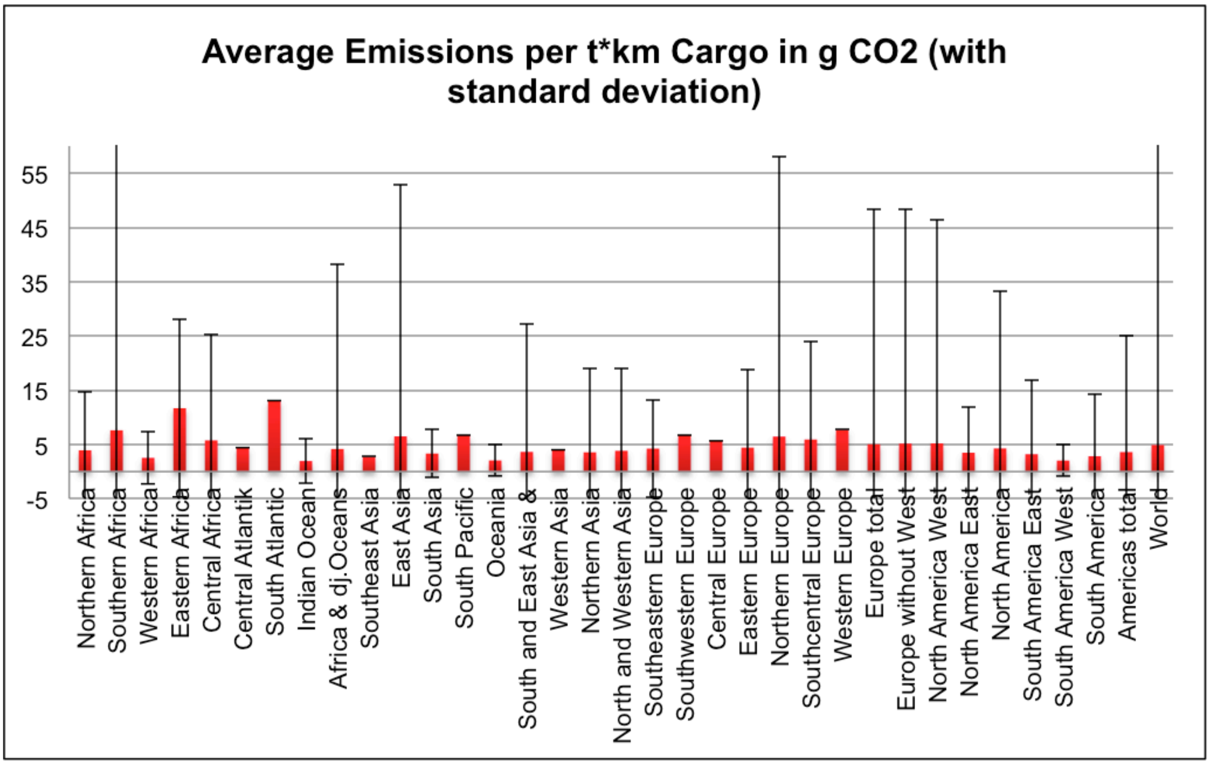



**Figure 3-6 Average $CO_2$ emission intensities in g/tkm by regions (with standard deviation)**

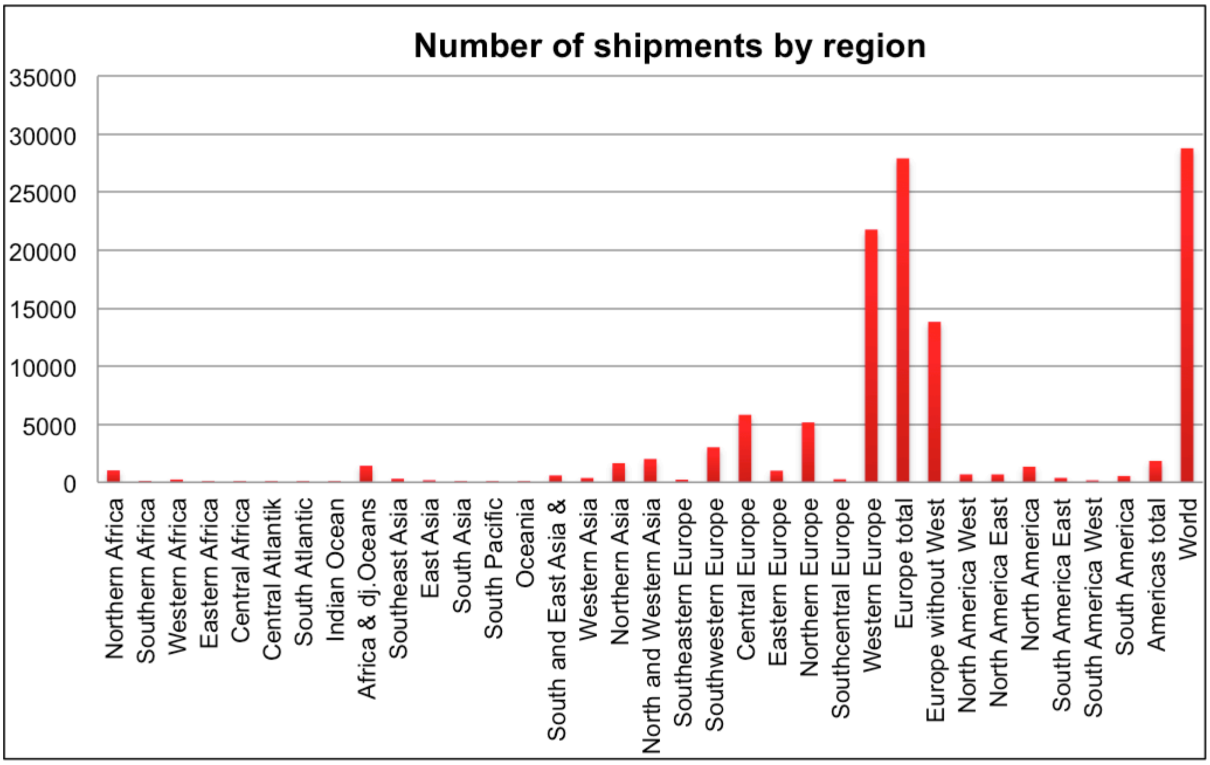



**Figure 3-7 Number of shipments by regions**

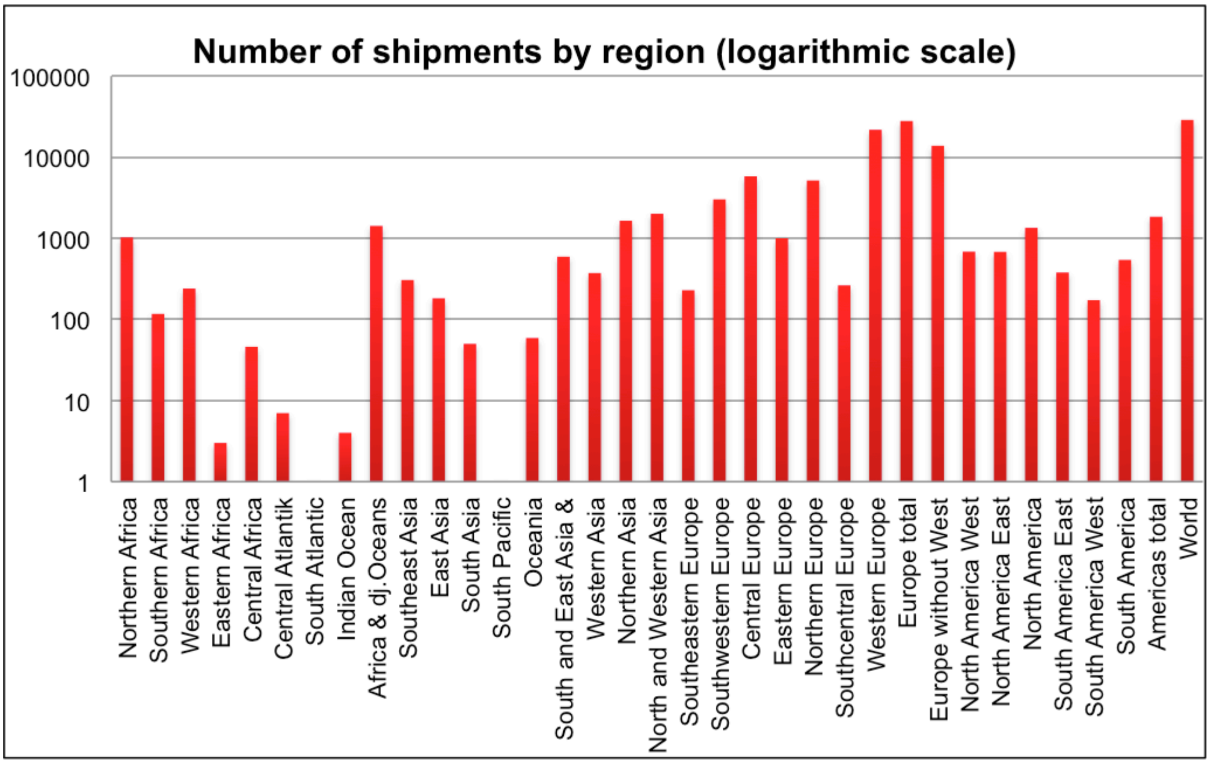



**Figure 3-8 Number of shipments by regions (logarithmic)**

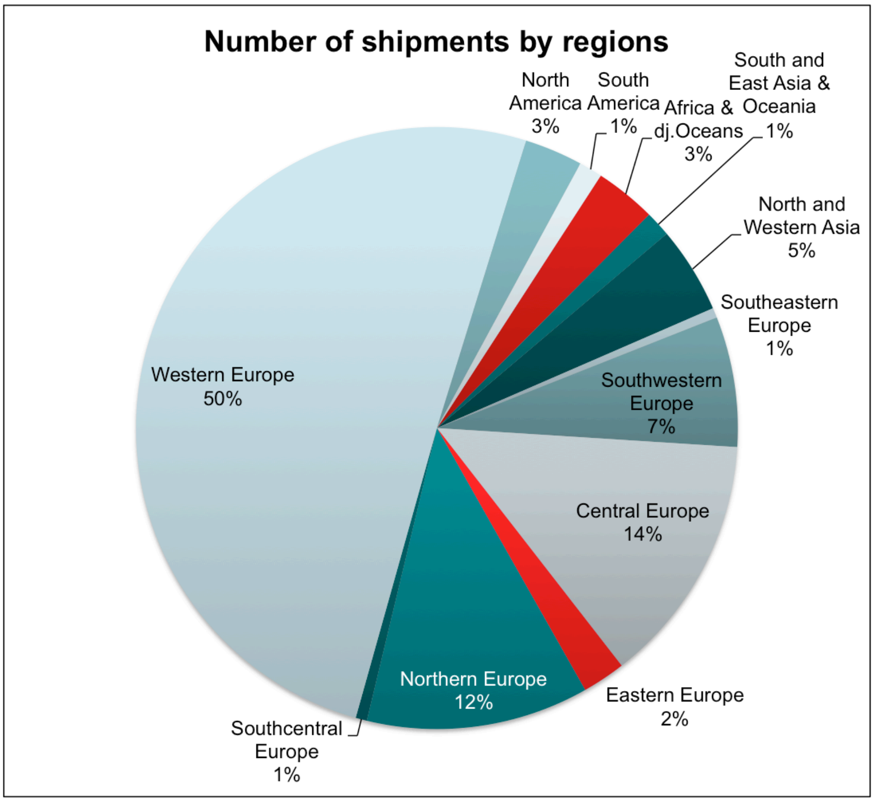



**Figure 3-9 Relative number of shipments by regions**

Total: 28 789 shipments, 21.5 Mt $CO_2$

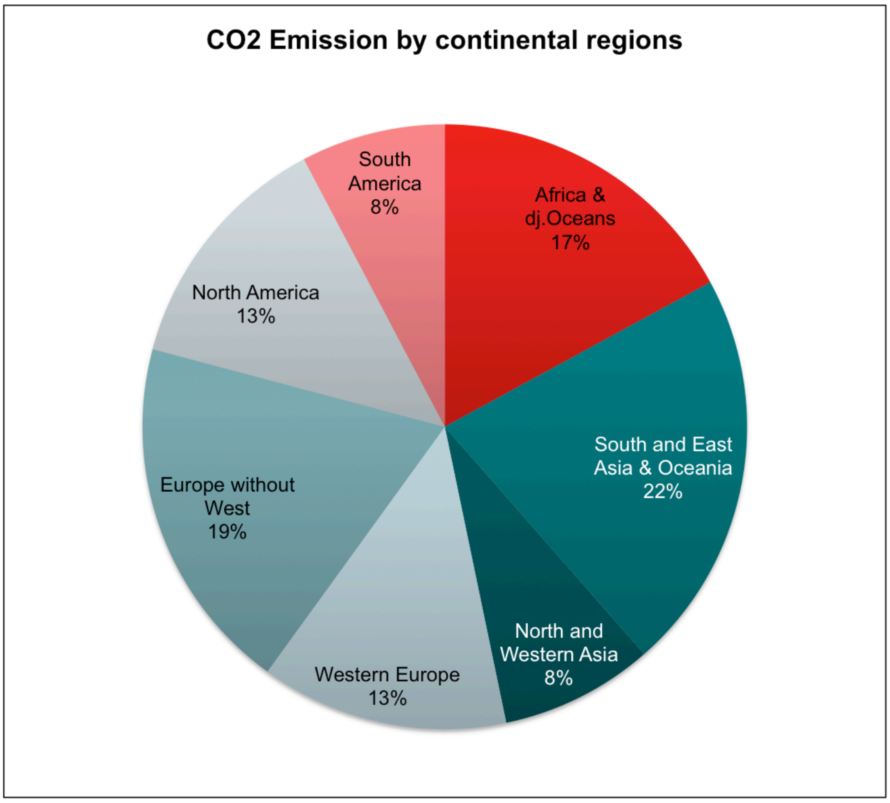



**Figure 3-10 Relative $CO_2$ emissions by larger regions/continents**

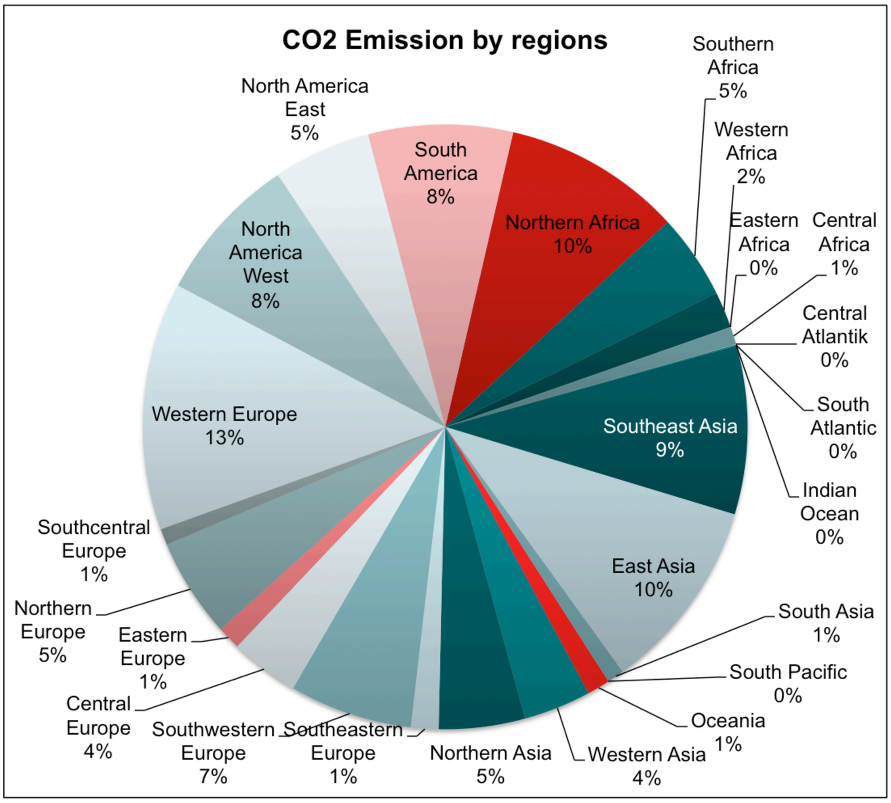



**Figure 3-11 Relative $CO_2$ emissions by regions**

## 3.2 Shipping types and modes

### 3.2.1 Shipping types in global perspective

The aggregate freight approach provides a sound overview of the goods changing modes of transport in Rotterdam. Table 3-7 provides an overview of these goods in respect to the broader categories, and whether these are discharged or loaded, graphic illustrations are provided in Figure 3-12.

**Table 3-7 Freight, tkm and $CO_2$ emission results from aggregate freight data**

| | Freight in Mt | | | 10^9 tkm | | | $CO_2$ emissions in Mt | | | $CO_2$ emission intensity |
|---|---|---|---|---|---|---|---|---|---|---|
| | discharged | loaded | total | discharged | loaded | total | discharged | loaded | total | in g/tkm |
| **Containers** | 54.1 | 55.6 | **109.6** | 597.5 | 477.6 | **1.075.1** | 3.14 | 2.42 | **5.56** | **5.17** |
| **Dry Bulk** | 79.9 | 9.4 | **89.3** | 723.3 | 22.1 | **745.4** | 2.63 | 0.10 | **2.73** | **3.66** |
| **Liquid Bulk** | 174.8 | 53.9 | **228.7** | 910.9 | 442.7 | **1.353.6** | 3.69 | 1.47 | **5.16** | **3.81** |
| **Other general cargo** | 12.2 | 9.9 | **22.1** | 66.9 | 95.9 | **162.8** | 0.35 | 0.46 | **0.80** | **4.92** |
| **Ro-ro** | 2.7 | 14.7 | **17.4** | 4.0 | 12.0 | **16.0** | 0.03 | 0.09 | **0.12** | **7.38** |
| **all freight** | **323.6** | **143.5** | **471.6** | **2 302.6** | **1 050.3** | **3 352** | **9.83** | **4.54** | **14.37** | **4.28** |
| **In percentage of respective total:** | | | | | | | | | | |
| **Containers** | **11.6%** | **11.9%** | **23.5%** | **17.8%** | **14.2%** | **32.1%** | **21.9%** | **16.8%** | **38.7%** | **121%** |
| **Dry Bulk** | **17.1%** | **2.0%** | **19.1%** | **21.6%** | **0.7%** | **22.2%** | **18.3%** | **0.7%** | **19.0%** | **85%** |
| **Liquid Bulk** | **37.4%** | **11.5%** | **49.0%** | **27.2%** | **13.2%** | **40.4%** | **25.7%** | **10.3%** | **35.9%** | **89%** |
| **Other general cargo** | **2.6%** | **2.1%** | **4.7%** | **2.0%** | **2.9%** | **4.9%** | **2.4%** | **3.2%** | **5.6%** | **115%** |
| **Ro-ro** | **0.6%** | **3.2%** | **3.7%** | **0.1%** | **0.4%** | **0.5%** | **0.2%** | **0.6%** | **0.8%** | **172%** |
| **all freight** | **69.3%** | **30.7%** | **100.0%** | **68.7%** | **31.3%** | **100.0%** | **68.4%** | **31.6%** | **100.0%** | **100%** |

It is apparent that ratio of incoming to outgoing containers is relatively balanced, while both dry and liquid bulk are primarily incoming goods. This hints at the fact that a large share of empty bulk transport ships are leaving Rotterdam, which are not accounted for in the aggregate freight approach (their $CO_2$ emissions are assumed to be zero). Roll on – roll off cargo is mostly outgoing from Rotterdam.

Due to these restrictions, the $CO_2$ emissions of incoming goods are more than twice as high as those of outgoing goods, without taking into account the emissions caused by the transport of goods that are only passing through Rotterdam, but stay on board the ships – these are not registered to this method of accounting, nor are other ships that do not carry cargo.

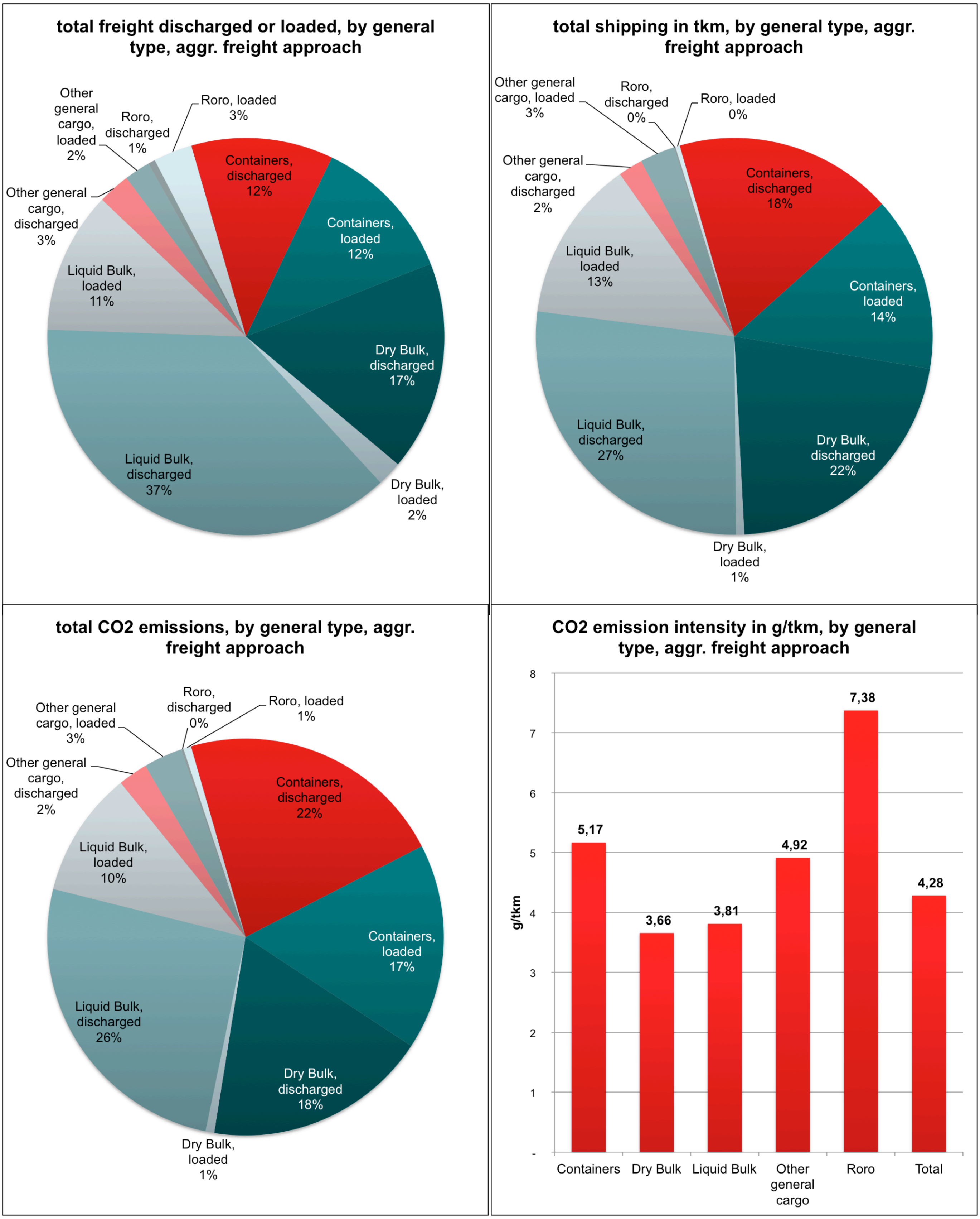



**Figure 3-12 Relative tonnages, tkm and $CO_2$ emissions and emission intensity of freight transferred in respect to type, via aggregate freight approach**

With the shipment-based first approach and differentiation by shipment type, the values appear mostly in line with the relative shares. Figure 3-13 to Figure 3-17 provide an overview.

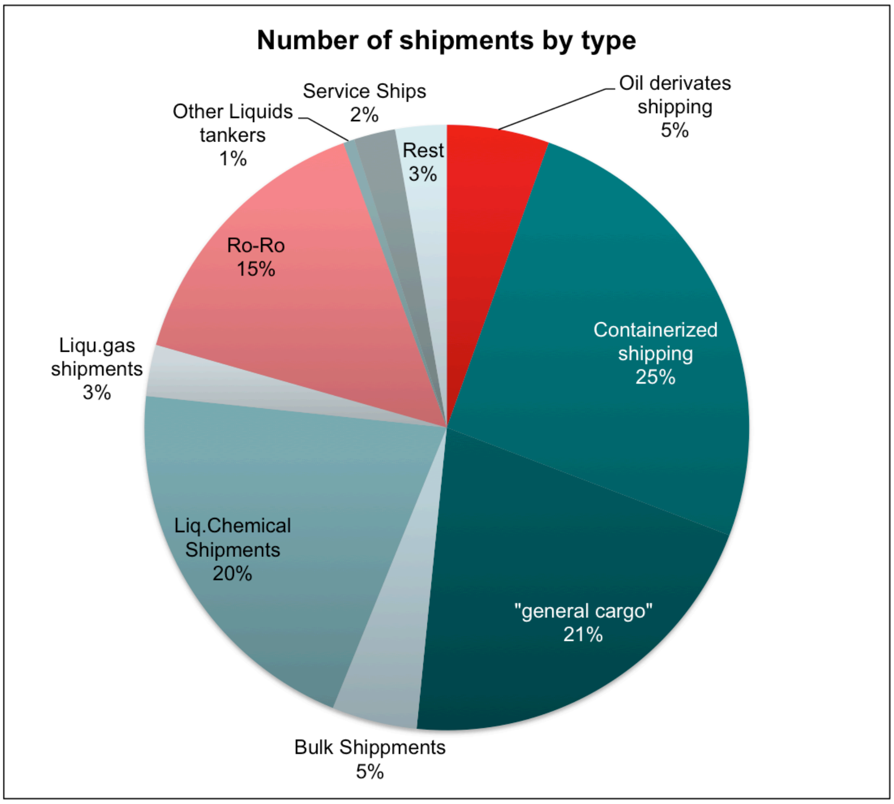



**Figure 3-13 Relative number of shipments by type**

In total, 28 789 shipments are listed for 2015 and are distributed according to Figure 3-13.

The $CO_2$ emission intensities are consistent with other and older sources, taking efficiency improvements into consideration. For the time period 1992-2000, the Swiss Ecoinvent Centre reports average $CO_2$ emission intensities of 4.0 g/tkm for transoceanic tankers (Ecoinvent 2012a) and 7.8 g/tkm for transoceanic freight ships (Ecoinvent 2012b).

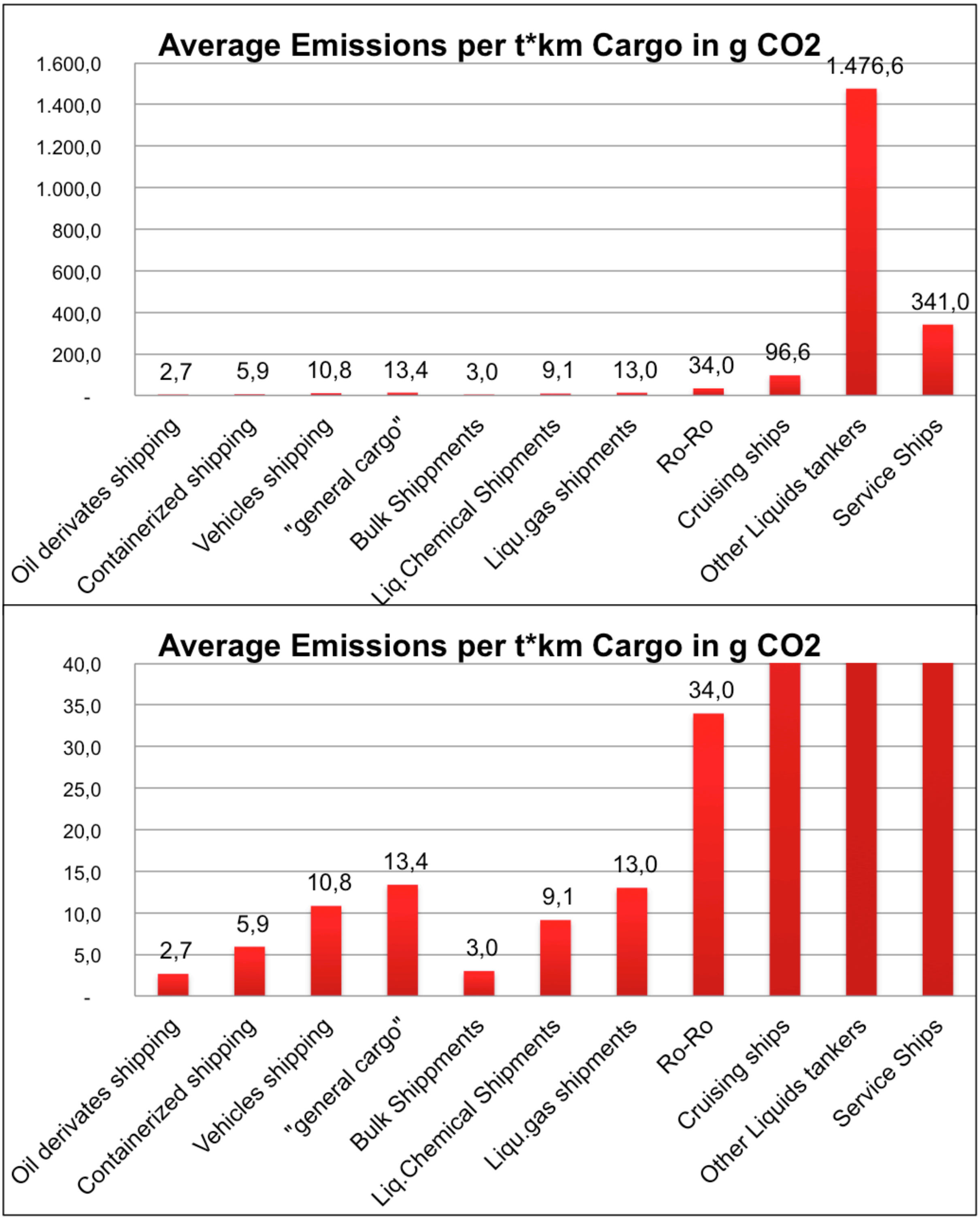



**Figure 3-14 $CO_2$ emission intensity in g/tkm, for different shipping types (two scales)**

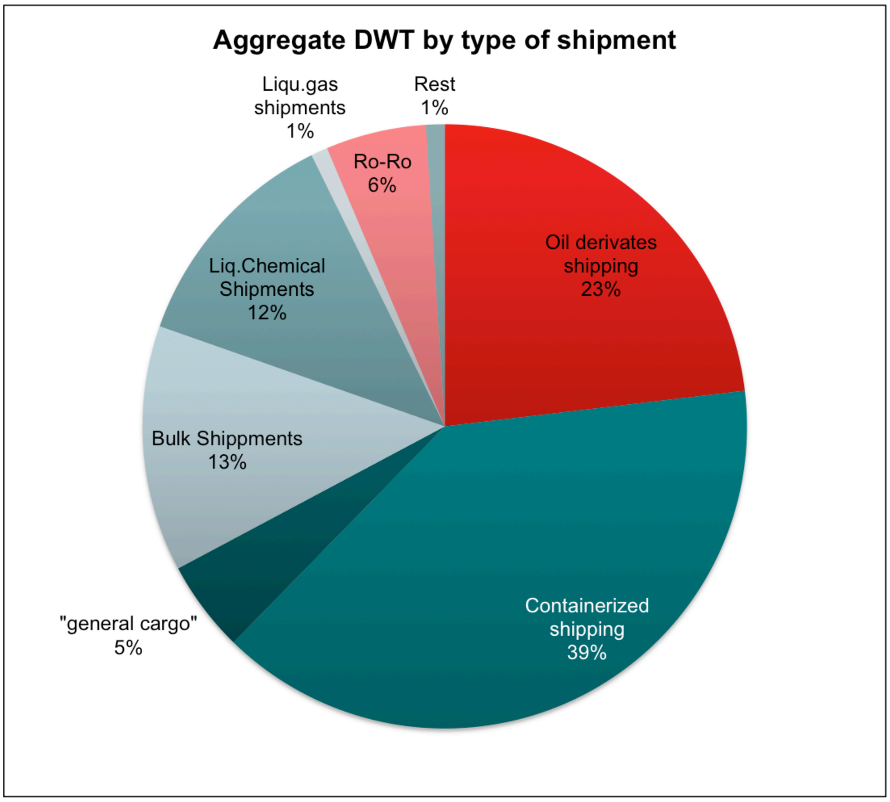



**Figure 3-15 Relative aggregate DWT by type of shipment**

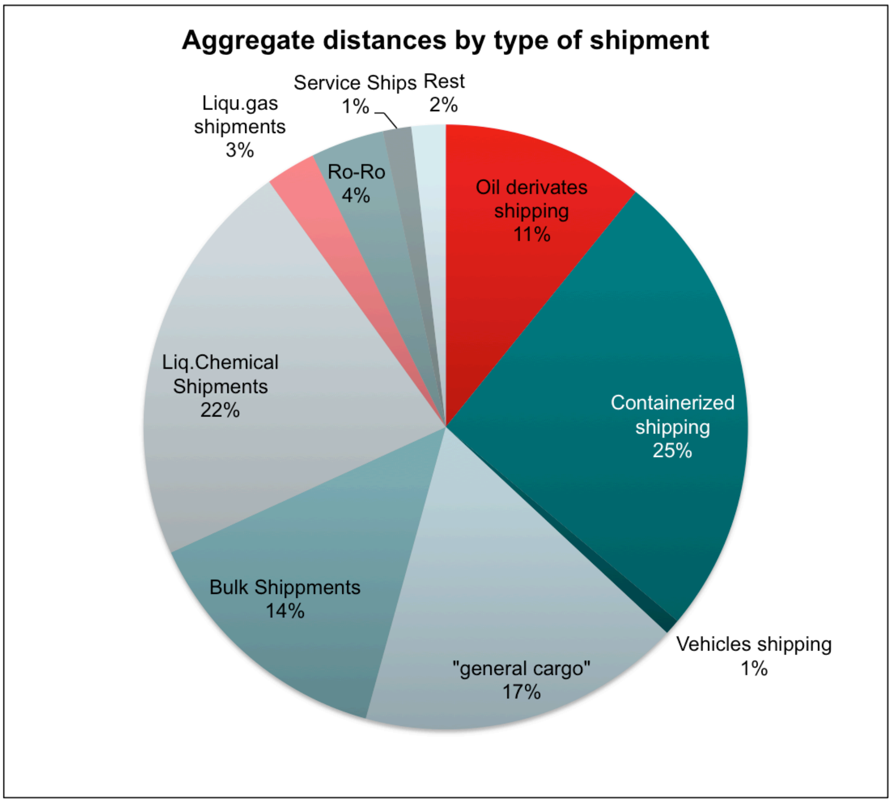



**Figure 3-16 Relative aggregate distances travelled by type of shipment**

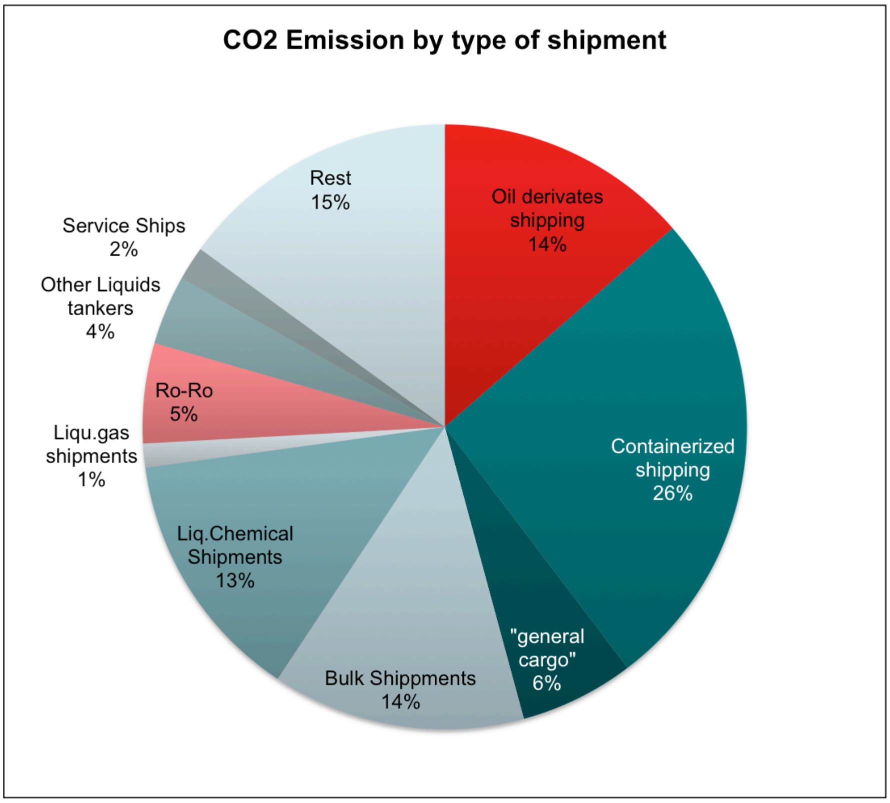



**Figure 3-17 Relative $CO_2$ emissions by type of shipment**

Total: 21.5 Mt $CO_2$

If empty shipments are included in the aggregate freight approach, the numbers change significantly. In line with the differentiation by shipment type, shown in Figure 3-12, there are large differences between the discharged and loaded amounts of freight, as well as for the corresponding tkm values and $CO_2$ emissions.

**Table 3-8 Differences in discharged and loaded bulk freight, in shares of the total volumes**

| | liquid bulk | | | dry bulk | | | |
|---|---|---|---|---|---|---|---|
| | **loaded** | **discharged** | **diff.** | **loaded** | **discharged** | **diff.** | **total diff.** |
| **Freight amount** | 11% | 37% | 26% | 2% | 17% | 15% | 41% |
| **tkm** | 13% | 27% | 14% | 1% | 22% | 21% | 35% |
| **$CO_2$ emissions** | 10% | 26% | 16% | 1% | 18% | 17% | 33% |

Empty ships show a relatively similar fuel consumption to fully loaded ships (Bialystocki und Konovessis 2016; Lu et al. 2013). It is therefore a reasonable estimation to add the estimated 33% of additional $CO_2$ emissions caused by the engines of empty bulk ships as they travel back to their ports of loading. With this, the total value of $CO_2$ emissions in the analysis via the aggregate freight approach raises by 33 %, from 14.4 Mt to 19.1 Mt $CO_2$.

In this correction, container ships and other less significant types of freight are not included. For container ships, it is less straight-forward to facilitate such an assessment, as these ships more commonly discharge or load only parts of their overall freight in one port at a time.

With this considerations, the $CO_2$ emissions in the adjusted aggregate freight approach account for 89 % of the emissions estimated using the shipment approach. Furthermore, the incoming and outgoing shipments display rather similar emissions. This is shown schematically in Figure 3-18.

If the same adjustment is done for all shipments (for each type, the larger value of the incoming or outgoing freight is selected, which is the incoming value for most goods), the overall emissions rise by 39 % to 20.0 Mt.

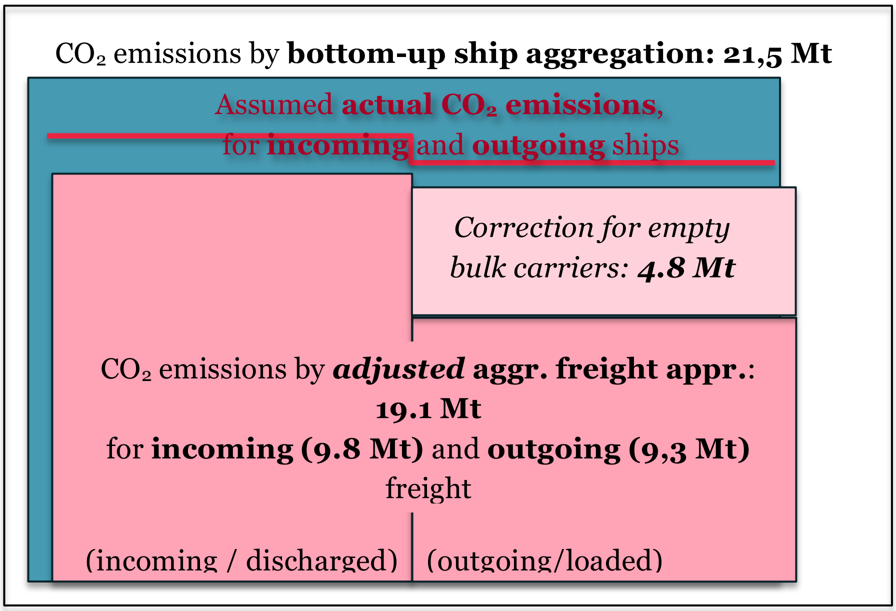



**Figure 3-18 Schematic representation of assessment approaches, with correction for adjusted aggregate freight approach**

These findings are also supported by other studies (ifeu et al. 2016), see Table 5-1 for an overview of the utilization factors for various ship types. While bulk carriers generally yield a utilization of slightly over 50 %, general cargo vessels are at 60 % and container and ro-ro vessels at 70 %. These figures are not included in the above assessment, but would further increase the fuel demand and emissions via the aggregate freight approach and would even go beyond the values of the bottom-up shipment approach. See an overview of both correction approaches in Table 3-9. As at least part of this adjustment represents a double-counting of already included inefficiencies, this value should only be considered as an additional and rough maximum estimate. The fuel demand and resulting emission intensity values of the IMO (IMO 2015) already include a part of these capacity (under)utilization factors.

**Table 3-9 Overview of emission corrections for the aggregate freight approach**

| | Initially assessed $CO_2$ emissions in Mt | | | With incoming/outgoing correction for bulk $CO_2$ emission in Mt | With incoming/outgoing correction for all cargo types $CO_2$ emission in Mt | With utilization correction $CO_2$ emission in Mt | |
|---|---|---|---|---|---|---|---|
| | dis-charged | loaded | total | * = adjusted | | utilization factors | Adjusted emission values |
| **Containers** | 3.14 | 2.42 | 5.56 | 5.56 | **6.28** | 70% | **7.94** |
| **Dry Bulk** | 2.63 | 0.10 | 2.73 | **5.26 *** | **5.26** | 55% | **4.96** |
| **Liquid Bulk** | 3.69 | 1.47 | 5.16 | **7.38 *** | **7.38** | 53% | **9.74** |
| **Other general cargo** | 0.35 | 0.46 | 0.80 | 0.80 | **0.92** | 60% | **1.33** |
| **Ro-ro** | 0.03 | 0.09 | 0.12 | 0.12 | **0.18** | 70% | **0.17** |
| **all freight** | 9.83 | 4.54 | 14.37 | **19.12 *** | **20.02** | 60% | **24.15** |
| In percentage of initial total emissions: | | | | | | | |
| **Containers** | 21.9% | 16.8% | 38.7% | 38.70% | **44%** | 70% | **55%** |
| **Dry Bulk** | 18.3% | 0.7% | 19.0% | **37% *** | **37%** | 55% | **35%** |
| **Liquid Bulk** | 25.7% | 10.3% | 35.9% | **51% *** | **51%** | 53% | **68%** |
| **Other general cargo** | 2.4% | 3.2% | 5.6% | 5.60% | **6%** | 60% | **9%** |
| **Ro-ro** | 0.2% | 0.6% | 0.8% | 0.80% | **1%** | 70% | **1%** |
| **all freight** | 68.4% | 31.6% | 100.0% | **133% *** | **139%** | 60% | **168%** |

Respective graphs are shown in Figure 3-19.

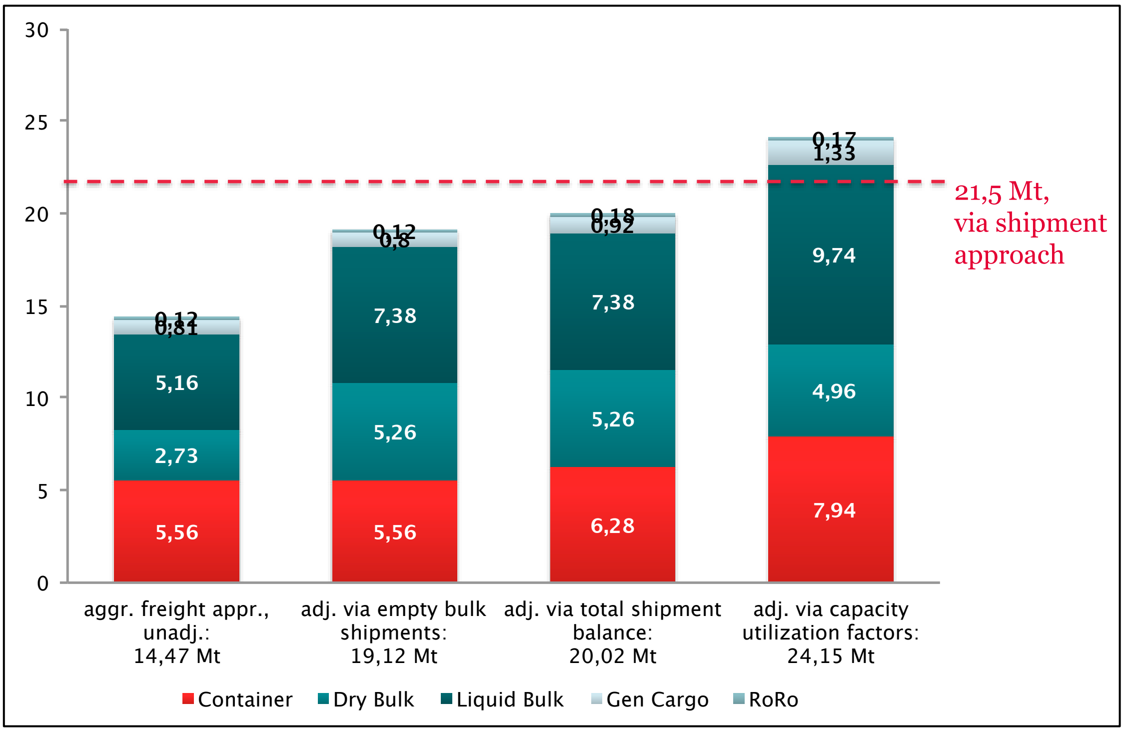



**Figure 3-19 $CO_2$ emission shares of shipping types for presented adjustments of the aggregate freight approach**

### 3.2.2 Deep sea vs. short sea shipping

While the number of short sea shipments widely exceeds that of deep sea shipments, as shown in the upper part of Figure 3-20, emissions are more evenly split with a slight overhang of deep sea shipping, as shown in the lower part of Figure 3-20, (12.04 Mt from deep sea shipping, compared to 9.42 Mt from short sea shipping).

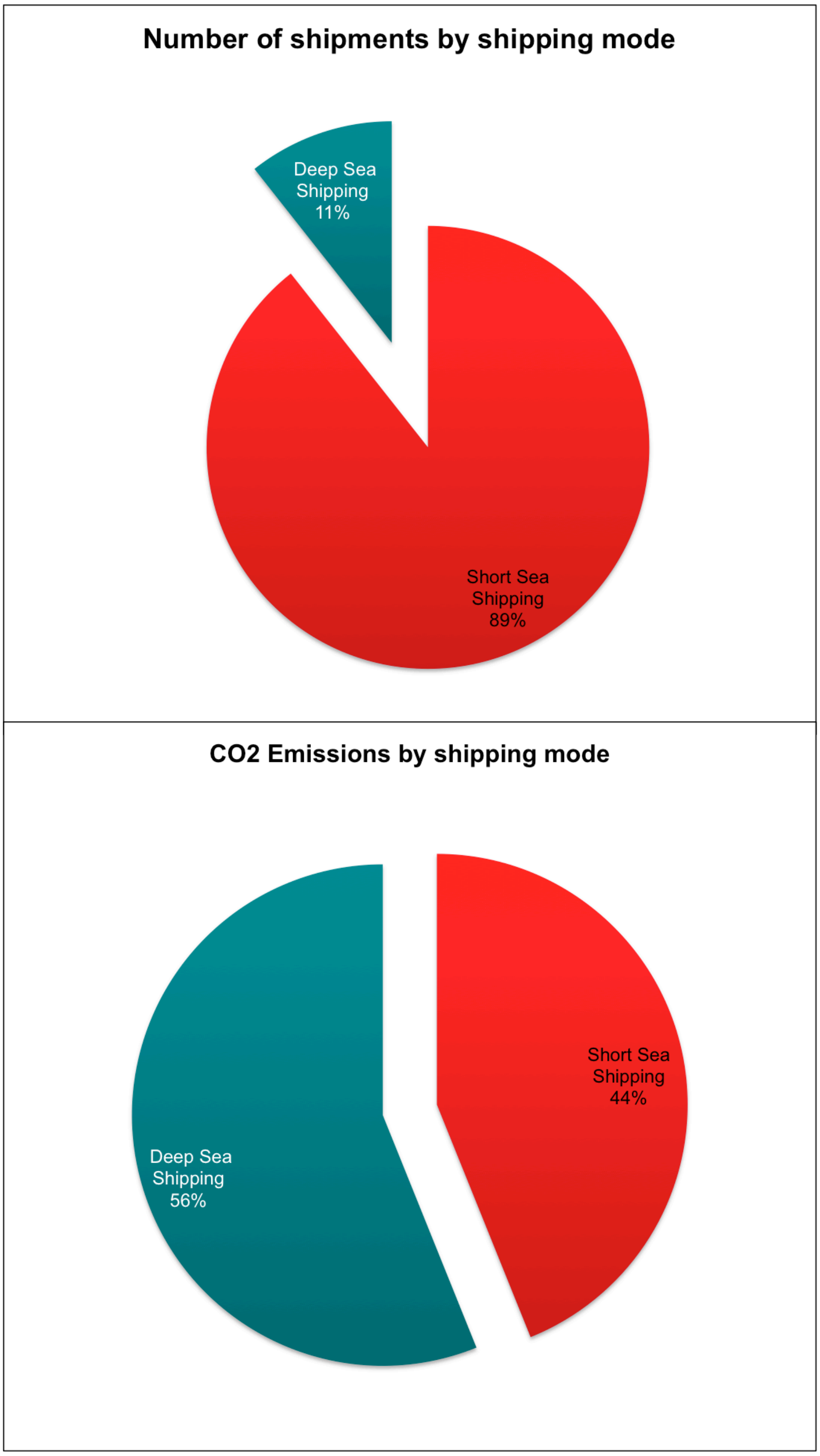



**Figure 3-20 Relative number and relative $CO_2$ emissions of shipments by mode**

The total evaluated shipment number for this is 28 789 shipments. In 2015, Rotterdam was the largest EU28 short sea shipping port with 8.2 % of the total weight of short sea shipping transport in the EU28 (Eurostat 2017). Table 3-10 provides a comparison of the gross weight goods reloaded in Rotterdam with those for the main ports in the EU28 region as a whole. As mentioned before, Eurostat data are comparable to the data underlying the aggregate freight approach.

**Table 3-10 Gross weight of goods transported to/from Rotterdam in comparison with EU, in Mt (Data: Eurostat 2017)**

| Year | Rotterdam: Gross weight via short sea shipping | EU ports: Short sea shipping | Rotterdam: Gross weight via deep sea shipping | EU ports: Deep sea shipping, | Rotterdam: total weight transported | EU ports: total weight transported | Rotterdam: unknown type | EU ports: unknown type |
|---|---|---|---|---|---|---|---|---|
| **2006** | 184.4 | 2 561.2 | 168.4 | 1 099.8 | 353.6 | 3 715.6 | 0.7 | 54.6 |
| **2007** | 186.2 | 2 613.3 | 186.6 | 1 152.4 | 374.2 | 3 824.3 | 1.4 | 58.6 |
| **2008** | 177.3 | 2 572.3 | 206.8 | 1 189.2 | 384.2 | 3 815.0 | 0.2 | 53.4 |
| **2009** | 173.3 | 2 318.4 | 180.4 | 984.8 | 353.9 | 3 357.4 | 0.1 | 54.2 |
| **2010** | 194.4 | 2 442.6 | 200.9 | 1 066.9 | 395.8 | 3 553.9 | 0.4 | 44.3 |
| **2011** | 172.3 | 2 438.8 | 206.8 | 1 148.3 | 396.5 | 3 648.1 | 17.4 | 61.0 |
| **2012** | 189.6 | 2 409.1 | 212.7 | 1 164.5 | 409.7 | 3 626.6 | 7.4 | 53.0 |
| **2013** | 188.2 | 2 400.3 | 216.7 | 1 179.3 | 414.8 | 3 633.9 | 10.0 | 54.3 |
| **2014** | 195.1 | 2 457.2 | 223.8 | 1 191.8 | 421.6 | 3 699.9 | 2.8 | 50.8 |
| **2015** | **203.7** | **2 485.0** | **219.9** | **1 181.8** | **436.9** | **3 760.2** | **13.3** | **93.5** |

The Eurostat numbers for freight transport in Table 3-10 are only around one forth of those derived from the Rotterdam ship data (here: total DWT 1627.3 Mt). This is due to the different assessment methods. Since Eurostat only uses data regarding the main ports (more than 1 Mt of goods or 200 000 passengers annually), the numbers should be too low, but the deviation from the aggregate freight approach (448.6 Mt) is within an acceptable range.

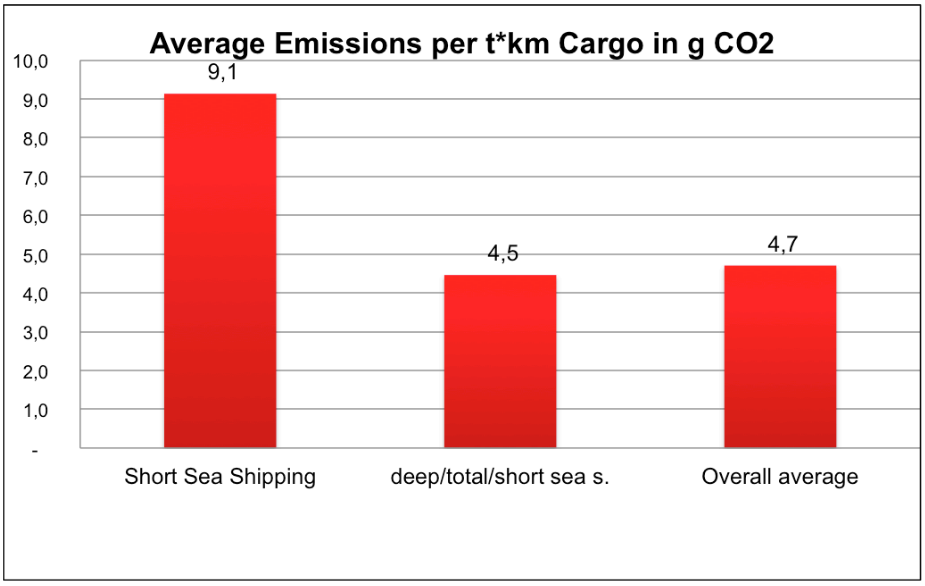
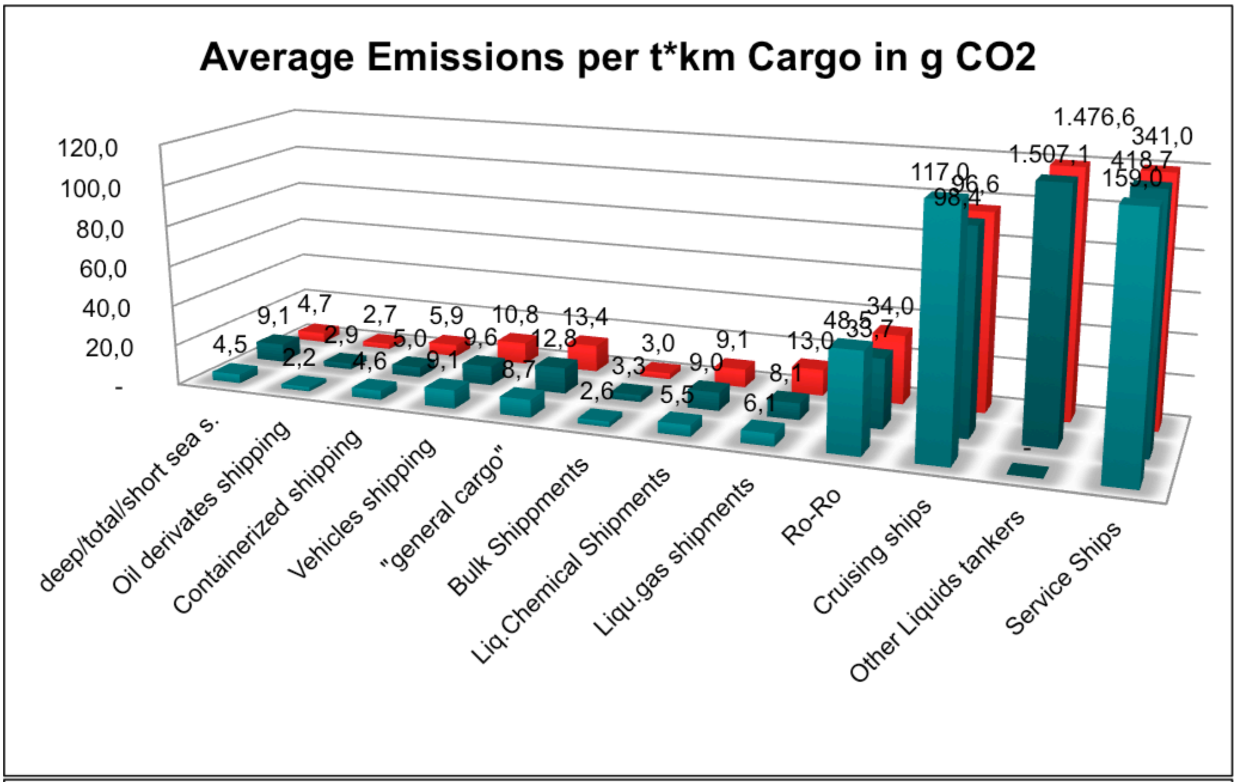
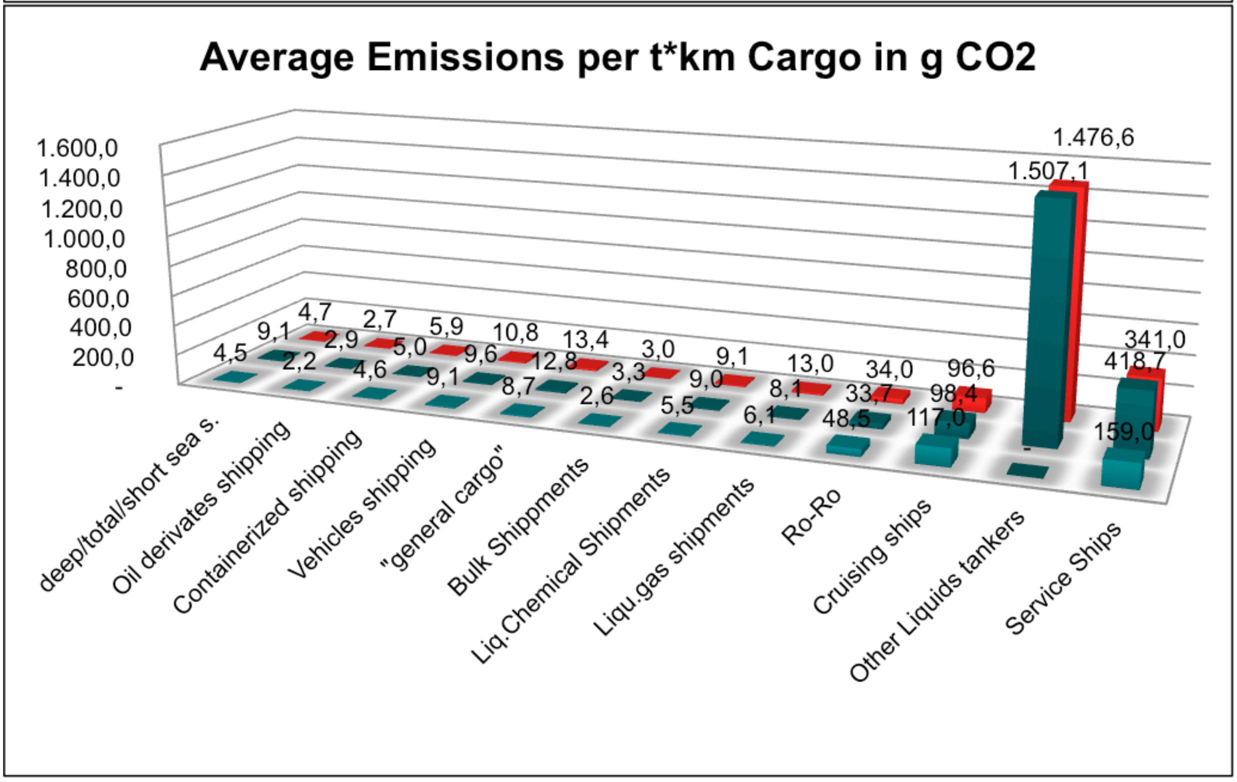



**Figure 3-21 $CO_2$ emission intensity in g/tkm, for different shipping modes**


Average Emissions per t*km Cargo in g CO2
120,0
100,0
80,0
60,0
40,0
20,0
-
deep/total/short sea s.
Oil derivates shipping
Containerized shipping
Vehicles shipping
"general cargo"
Bulk Shippments
Liq.Chemical Shipments
Liqu.gas shipments
Ro-Ro
Cruising ships
Other Liquids tankers
Service Ships


Average Emissions per t*km Cargo in g CO2
1.600,0
1.400,0
1.200,0
1.000,0
800,0
600,0
400,0
200,0
-
deep/total/short sea s.
Oil derivates shipping
Containerized shipping
Vehicles shipping
"general cargo"
Bulk Shippments
Liq.Chemical Shipments
Liqu.gas shipments
Ro-Ro
Cruising ships
Other Liquids tankers
Service Ships

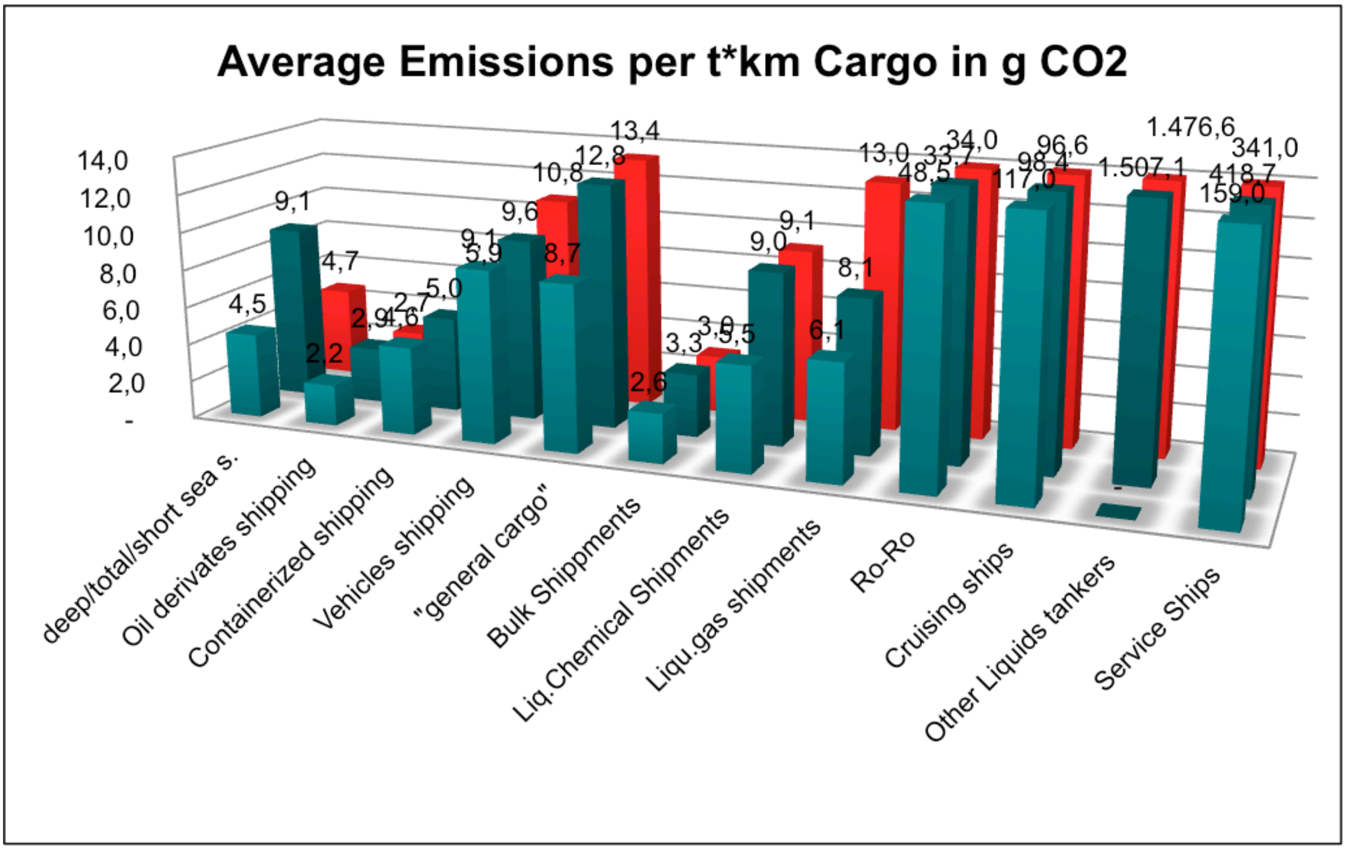



Figure 3-22 $CO_2$ emission intensity in g/tkm, for different shipping modes and types. Green: total shipments; red: deep sea s.; blue: short sea shipping (three scales)

While the total $CO_2$emissions of deep sea shipping are visibly higher than those of short sea shipping (see Figure 3-20), the emission intensity is reverse, as shown in Figure 3-21: while deep sea shipping emits 4.5 g/tkm, European short sea shipping has about double this value, with 9.1 g/tkm. The overall average emission intensity is with 4.7 g/tkm close to the one from deep sea shipping. This is largely due to the much smaller vessels with an average DWT of 22 833 t for short sea shipping, vs. 75 797 t for deep sea shipping. The very high emission intensities (see Figure 3-22) for cruising ships and service vessels are understandable due to their small cargo capacity. The extremely high values for “other liquid tankers” appear to require further investigation, but might be an artifact of the inland-bound transports. Roll-on-roll-off cargo is a rather emission intensive mode of transport, that has its primary advantages in fast loading and discharging. Innovations in improved modal transfer technologies might help reduce these emissions.

### 3.2.3 Deep sea shipping, differentiated by type

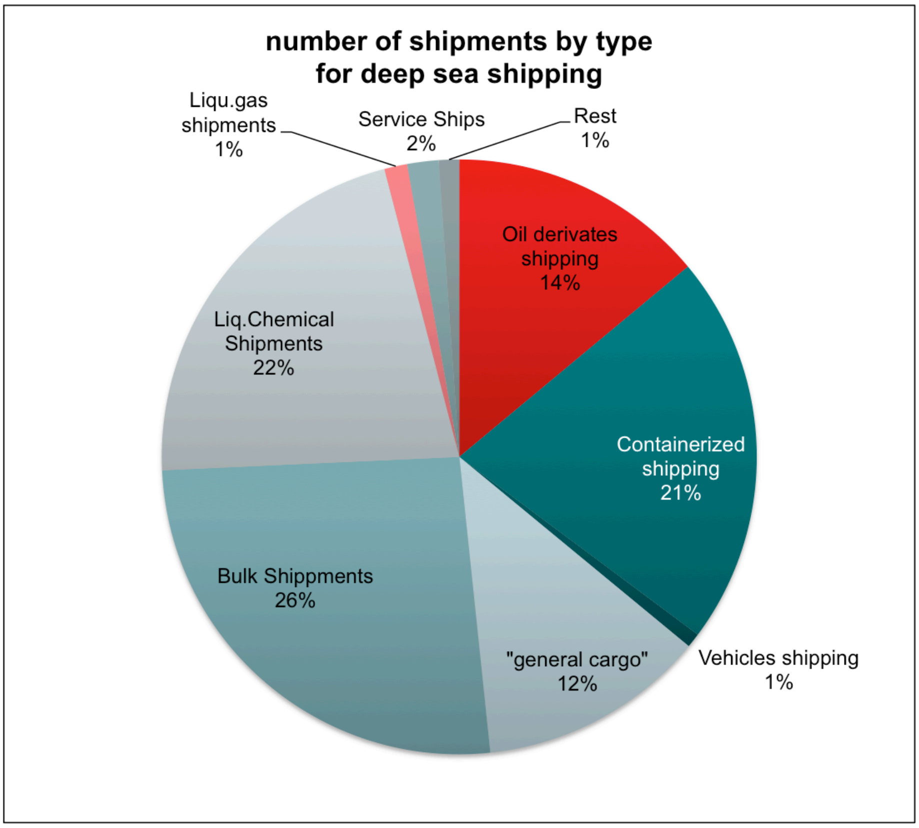



**Figure 3-23 Relative number of shipments by type, for deep sea shipping**

The total number of deep sea shipments is with 3030 shipments much smaller than the one for short sea shipping. The most of these consist of bulk shipments.

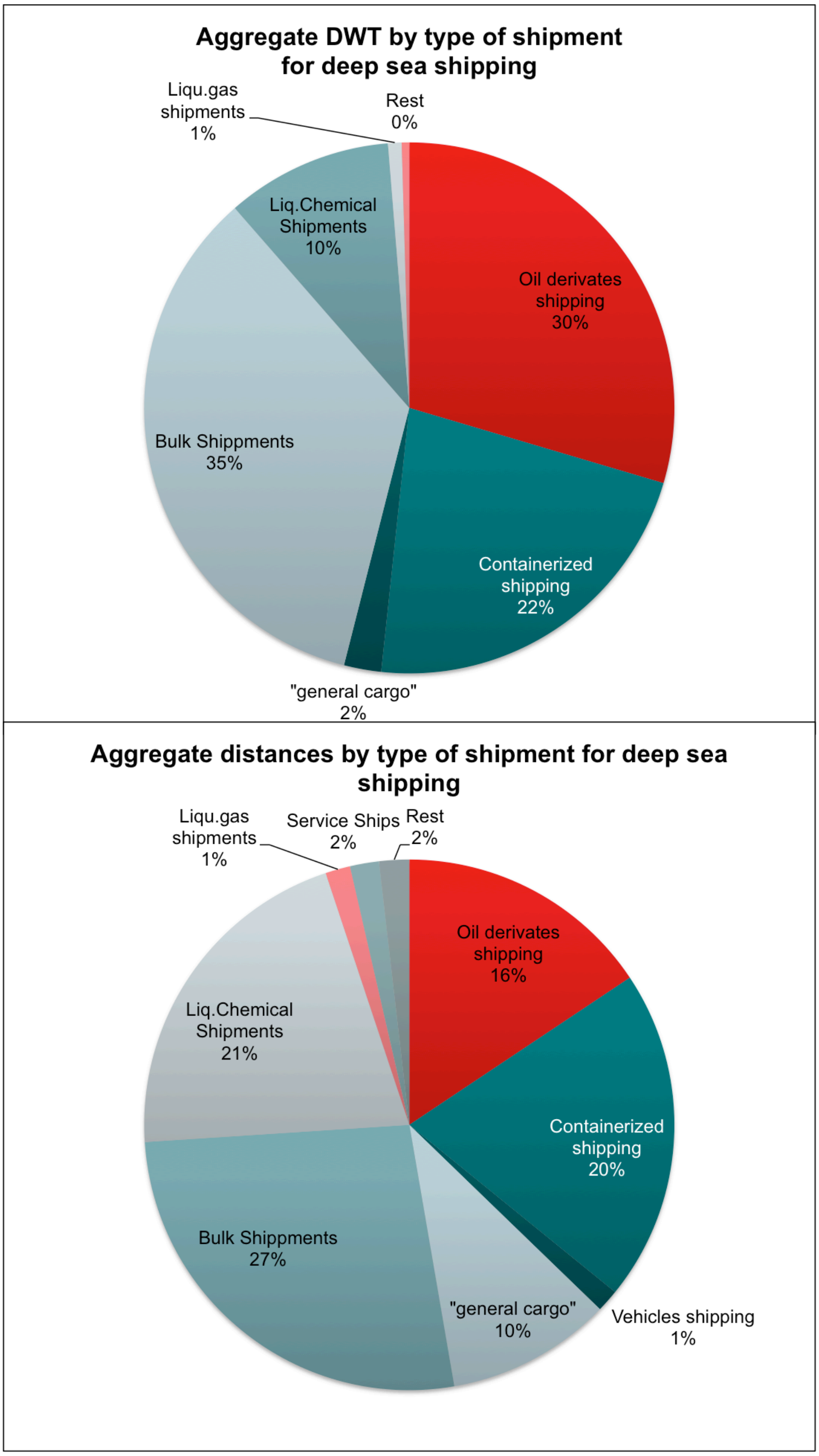



**Figure 3-24 Relative aggregate deadweight tonnage and distances travelled by type of shipment, for deep sea shipping**

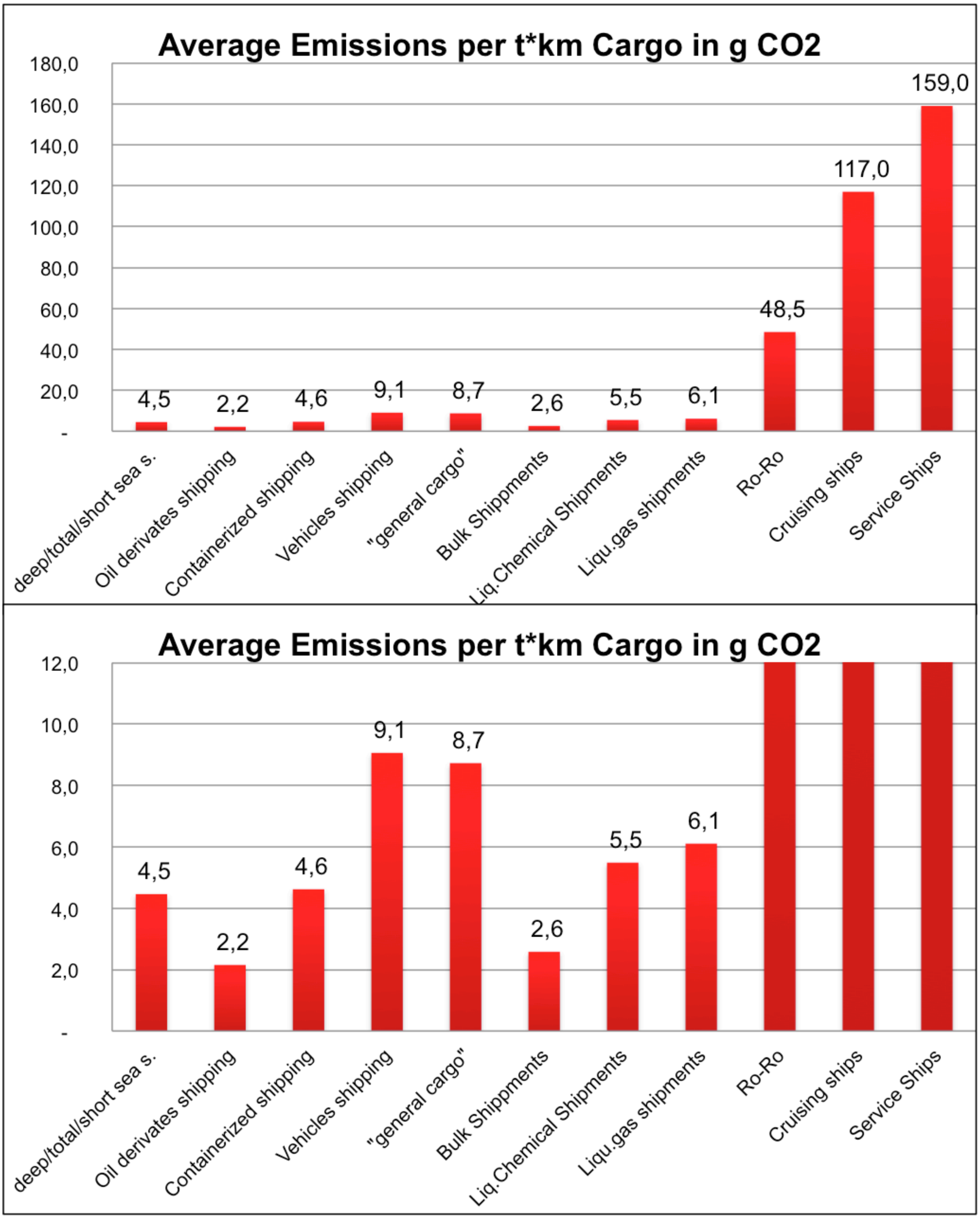



**Figure 3-25 $CO_2$ emission intensity in g/tkm, for different shipping types for deep sea shipping (two scales)**

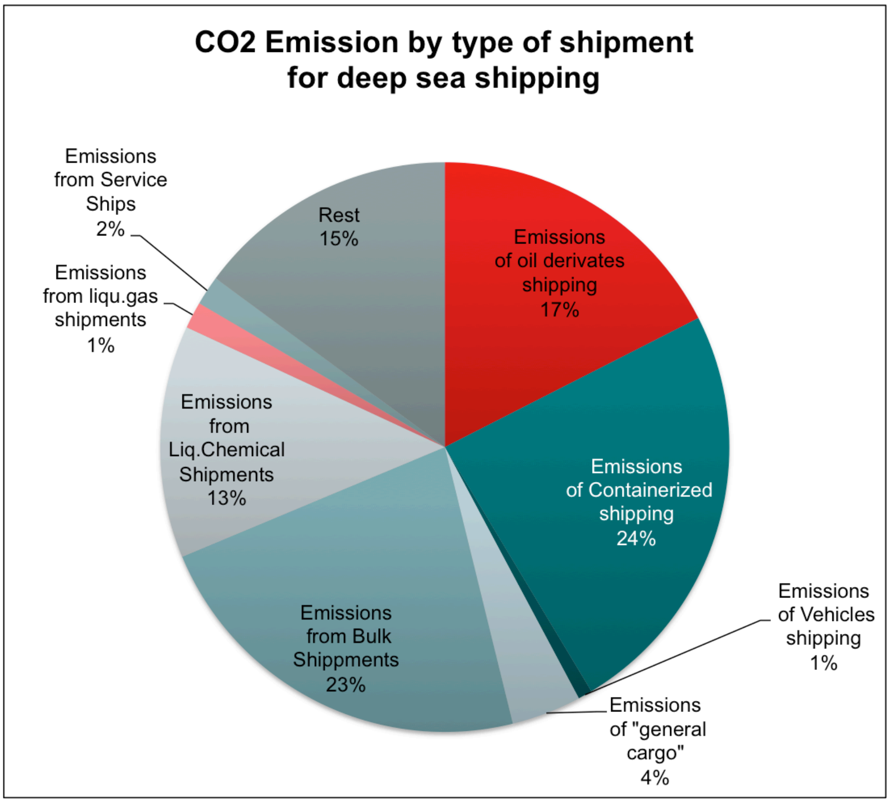



**Figure 3-26 Relative $CO_2$ emissions by type of shipment, for deep sea shipping**

With a total of 12.04 Mt $CO_2$, bulk shipments take up about half of these. Fossil bulk (oil derivates, gas and coal) are a substantial part of deep sea shipping.

### 3.2.4 Short sea shipping, differentiated by type

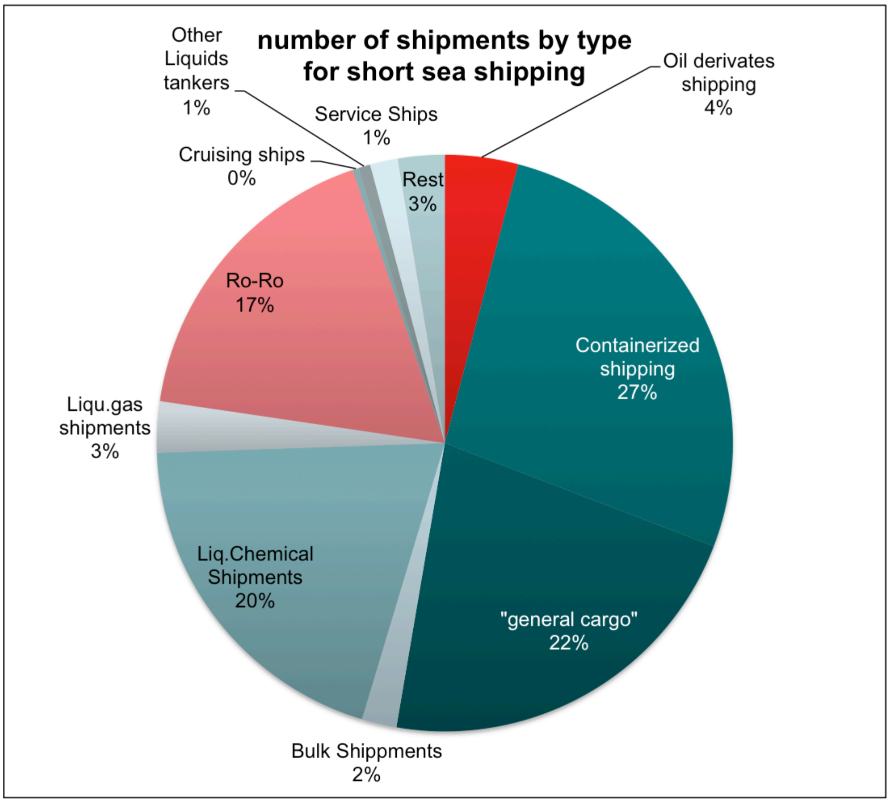



**Figure 3-27 Relative number of shipments by type, for short sea shipping**

With 24 172 shipments in 2015, European short sea shipping causes the brunt of Rotterdam's discharging and loading activities. In terms of shipments as shown in Figure 3-27, bulk makes up about half of all shipments. In terms of DWT, this split appears to stay roughly the same. This is in contrast with the Eurostat data shown in Table 3-11, where containerized shipping appears to be negligible or non-existent. This aspect might require further investigation. In terms of $CO_2$ emissions (total: 9.44 Mt $CO_2$) bulk takes up the largest share, as shown in Figure 3-31.

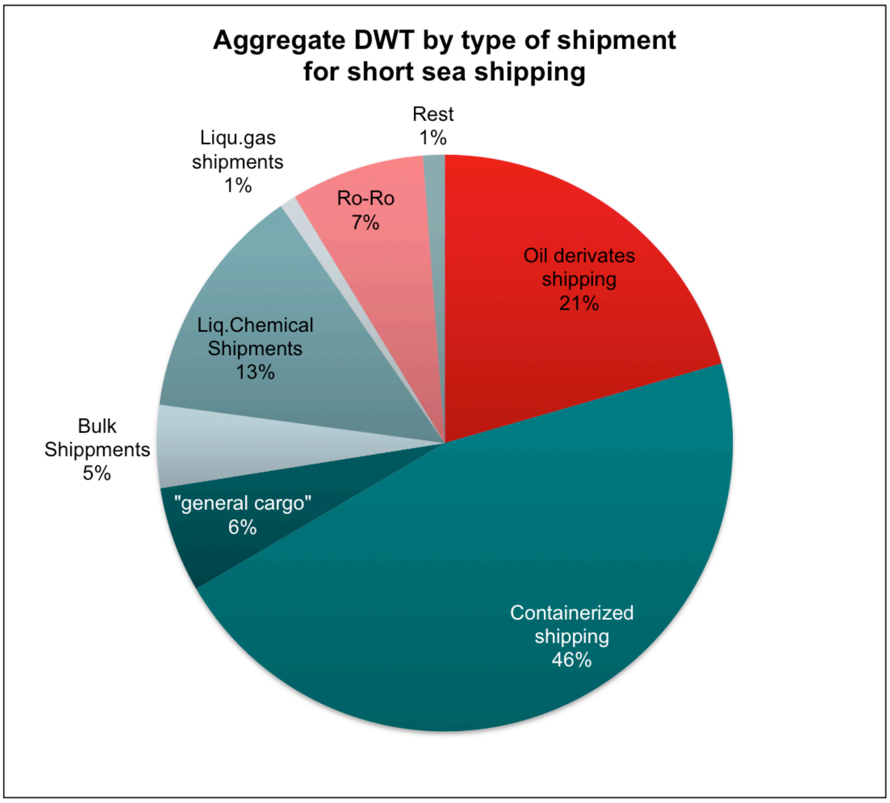



**Figure 3-28 Relative aggregate deadweight tonnage by type of shipment for short sea shipping**

**Table 3-11 Gross weight of goods transported to/from main ports, by short sea shipping, by type of cargo, Netherlands in comparison with EU, in Mt (Data: Eurostat 2017)**

| | Total | | liquid bulk goods | | Dry bulk goods | | liquid bulk goods | | Ro-Ro | | Other cargo | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Nether-lands | EU28 | Netherl er-lands | EU28 | Nether-lands | EU28 | Nether-lands | EU28 | Nether-lands | EU28 | Nether-lands | EU28 |
| 2006 | 253.0 | 1 834.9 | 150.7 | 907.1 | 39.8 | 365.4 | 29.6 | 192.5 | 15.4 | 233.6 | 17.4 | 161.4 |
| 2007 | 259.3 | 1 865.5 | 153.1 | 904.1 | 42.7 | 364.7 | 31.0 | 209.2 | 15.4 | 247.5 | 17.1 | 139.9 |
| 2008 | 250.8 | 1 861.8 | 149.3 | 899.9 | 41.1 | 364.6 | 29.8 | 217.6 | 15.3 | 239.1 | 15.2 | 140.7 |
| 2009 | 243.8 | 1 691.2 | 151.6 | 843.7 | 37.3 | 340.1 | 27.1 | 196.4 | 12.9 | 202.8 | 14.9 | 108.1 |
| 2010 | 275.9 | 1 764.7 | 164.8 | 854.7 | 47.4 | 344.6 | 33.7 | 211.2 | 13.9 | 228.6 | 16.2 | 125.6 |
| 2011 | 242.3 | 1 787.1 | 147.3 | 829.1 | 46.7 | 359.4 | 32.5 | 231.8 | 5.5 | 238.5 | 10.3 | 128.3 |
| 2012 | 265.6 | 1 775.9 | 155.2 | 816.3 | 39.1 | 356.1 | 34.9 | 241.3 | 17.6 | 233.9 | 18.8 | 128.4 |
| 2013 | 262.9 | 1 756.6 | 148.4 | 785.8 | 39.2 | 349.0 | 33.6 | 248.8 | 15.9 | 237.8 | 25.8 | 135.1 |
| 2014 | 272.1 | 1 791.6 | 155.8 | 780.6 | 40.1 | 364.5 | 34.6 | 268.0 | 16.4 | 239.5 | 25.2 | 139.1 |
| **2015** | **286.2** | **1 808.5** | **166.7** | **811.8** | **44.4** | **364.0** | **32.5** | **263.8** | **18.4** | **246.0** | **24.3** | **208.7** |
| 2015 % of total | 100% | 100% | 58.2% | 44.9% | 15.5% | 20.1% | 11.4% | 14.6% | 6.4% | 13.6% | 8.5% | 11.5% |

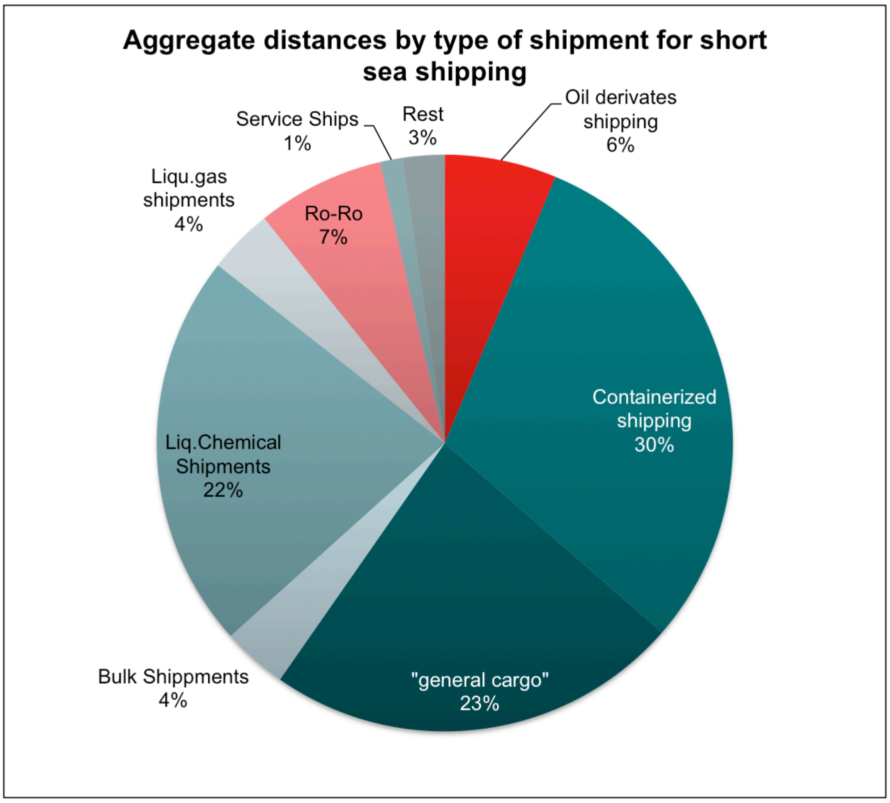



**Figure 3-29 Relative aggregate distances travelled by type of shipment, for short sea shipping**

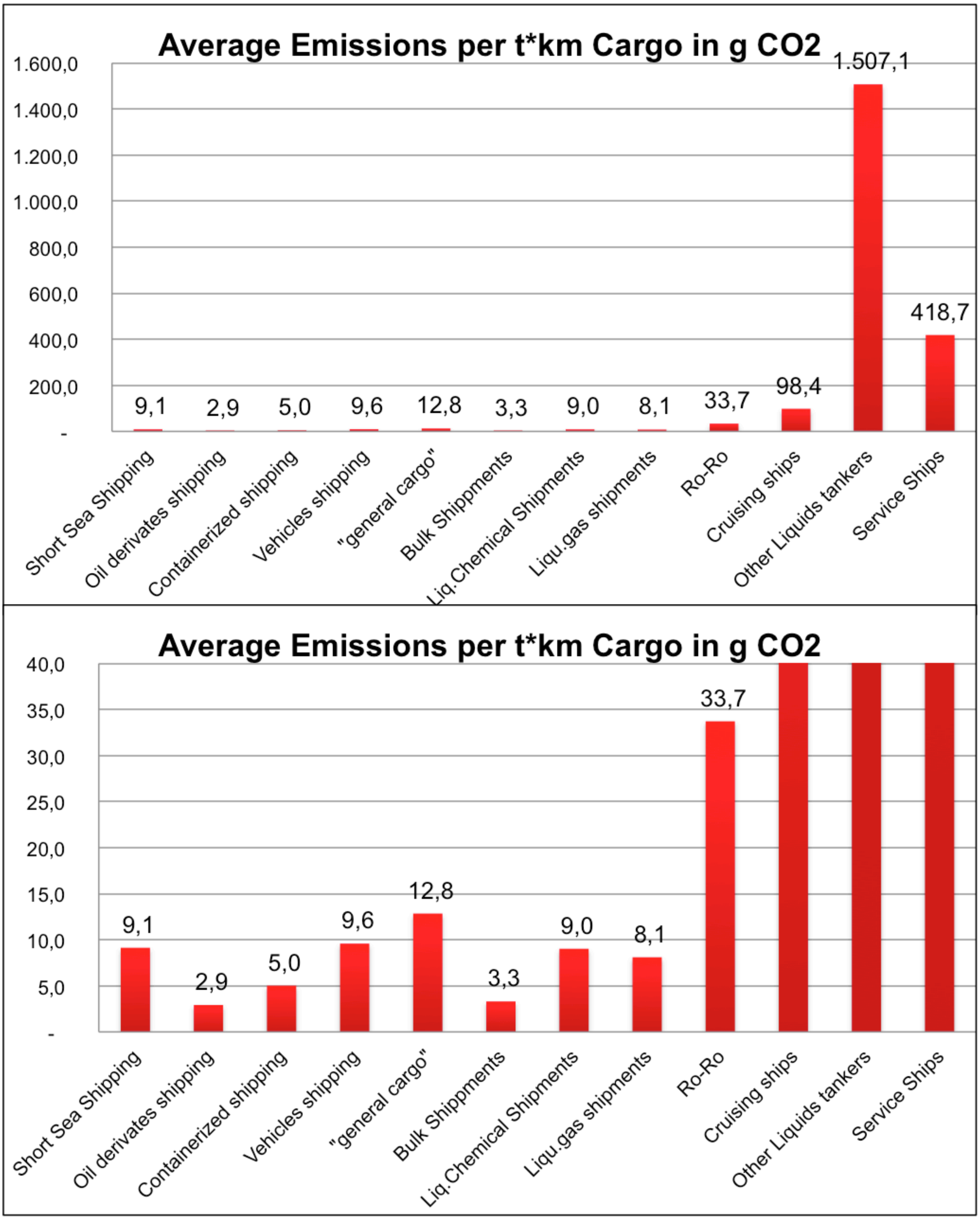



**Figure 3-30 $CO_2$ emission intensity in g/tkm, for different shipping types for short sea shipping (two scales)**

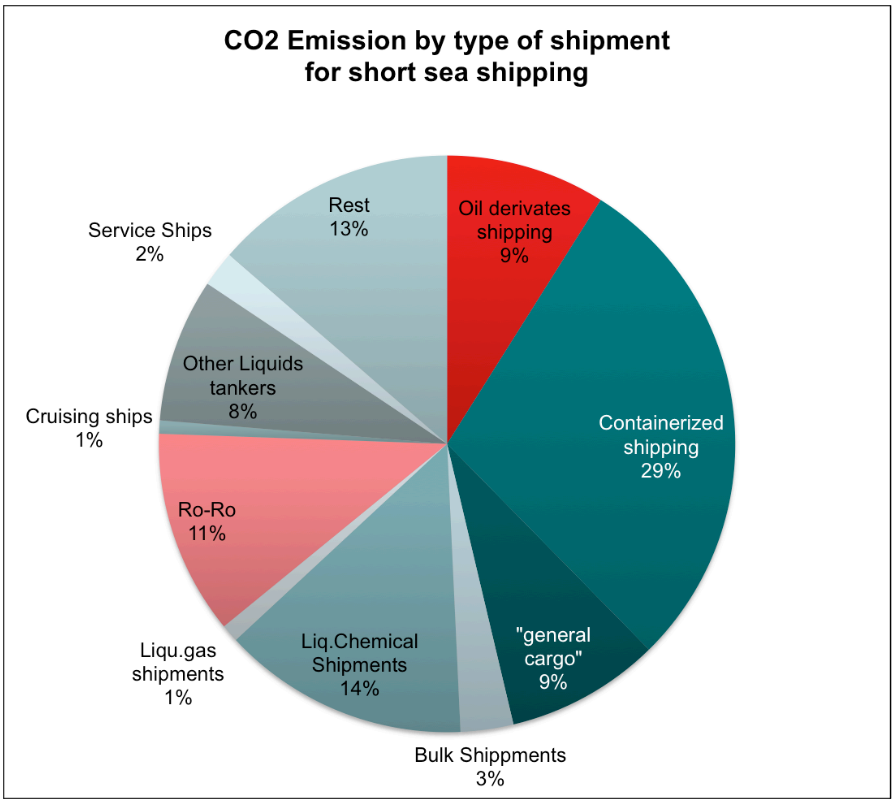



**Figure 3-31 Relative $CO_2$ emissions by type of shipment, for short sea shipping**

# 4 In-Port Emissions

Additionally to the assessment of the maritime $CO_2$ emissions which make up the by far largest share, we conducted an assessment of the emissions of hinterland transport (see report 4.2) and in-port activities. For both of these fields, literature values were used and combined with the data about freight tonnages and tkm supplied by the Port. Further details about the assessments are given within each of the following sections for the specific part of in-port activities.

Total $CO_2$ emissions for container logistics within the Port of Rotterdam in 2015 are estimated by CE Delft to have been 961 kt. These were seen to consist of 584 kt for maritime transport, 43 kt for inland ships, 7 kt for rail transport, 114 kt for road freight and 214 kt for the handling of goods within the port. (den Boer et al. 2017, p. 5, 7)

Note however, that these estimates cover only the container activities of the port.

As shown in Figure 3-12, containerized freight makes up about 25 % of overall freight discharged or loaded in Rotterdam, while liquid bulk takes up about 50 % and dry bulk most of the rest. While liquid bulk is overall the most energy-efficient to handle, it is reasonable to assume that the overall $CO_2$ emissions for in-port operations should be at least twice as high as those of pure container handling.

When comparing with the Hamburg port, which has a freight throughput of about 150 Mt, Rotterdam with its 453 Mt annual freight throughput should yield about 1.3 Mt of annual $CO_2$ emissions altogether for handling, re-loading of cargo, tugboats and berthed ships.

## 4.1 Berthed Ships

The $CO_2$ emissions from berthed ships above 100 GT in Rotterdam accounted in 2014 for 612 kt $CO_2$ (Marin 2016, p. 40).

## 4.2 Handling of Goods

This category subsumizes all types of on-shore handling of goods, including cranes, trucks, conveyor belts, storage tanks and the like. Due to the large variety of emission sources, this category is necessarily incomplete and yields a potentially large margin of error. As a rough estimate, this could be up to 50 %. Data was provided by the Port of Rotterdam, that accumulated to roughly 450 kt of $CO_2$, for which then a margin of error of +/- 200 kt was set.

## 4.3 In-Port Traffic

The $CO_2$ emissions of sailing ships over 100 GT accounted for 203 kt in 2014 (Marin 2016, p. 40). Note, however, that a large part of these emissions should already be included in the emission statistic for seagoing ships in the previous chapters and depend mostly on the drawn system boundary (the border of the port area). Therefore, these emissions were not additionally included in this assessment. Emissions from tug boats were not differentiated, but should be significantly lower than emissions from sailing seagoing freight vessels.

## 4.4 Total In-Port Emissions and Conclusion

Adding up, berthed ships are the most significant contributor of in-port emissions with 612 kt of $CO_2$. At the same time, these should also be the simplest to be avoided via shore-side electric energy supply systems. As the energy demand has comparably little volatility and power lines can be used, these systems do not require large-scale energy storage and can be installed gradually.

The other large share is due to handling on land, including cranes, trucks and storage tanks, with about 450 kt +/- 200 kt. Depending on the operation mode, electrification appears realistic either via battery-electric systems or direct electrification.

For further sources such as tug boats, an additional 70 kt +/-50 kt have been added as a rough estimate, below the value of sailing freight ships within the port. Since these are mostly short-distance operation, it appears to be reasonable to assume that the combustion engines of these ships could be the first ones to be completely replaced be emission-neutral aggregates such as electric battery systems or hydrogen fuel cells.

This adds up to 1130 +/- 250 kt $CO_2$ for all in-port emissions, which can be completely avoided with significant investments through appropriate technological improvements. The more parts are switched to direct electricity usage, the lower the overall energy demand for these operations, as losses and inefficiencies are reduced.

# 5 Annex: Other Data

| Ship type | Size category | Units | Number active | | Decimal AIS coverage of in-service ships | Avg. dead-weight (tonnes) | Avg. installed power (kW) | Avg. design speed (knots) | Avg. days at sea | Avg.* sea speed (knots) | Avg.* consumption ('000 tonnes) | | | Total $CO_2$ emissions ('000 tonnes) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | IHSF | AIS | | | | | | | Main | Auxiliary | Boiler | |
| Bulk carrier | 0–9,999 | dwt | 1,216 | 670 | 0.55 | 3,341 | 1,640 | 11.6 | 167 | 9.4 | 0.9 | 0.5 | 0.1 | 5,550 |
| | 10,000–34,999 | dwt | 2,317 | 2,131 | 0.92 | 27,669 | 6,563 | 14.8 | 168 | 11.4 | 3.0 | 0.5 | 0.1 | 24,243 |
| | 35,000–59,999 | dwt | 3,065 | 2,897 | 0.95 | 52,222 | 9,022 | 15.3 | 173 | 11.8 | 4.0 | 0.7 | 0.1 | 44,116 |
| | 60,000–99,999 | dwt | 2,259 | 2,145 | 0.95 | 81,876 | 10,917 | 15.3 | 191 | 11.9 | 5.4 | 1.1 | 0.3 | 45,240 |
| | 100,000–199,999 | dwt | 1,246 | 1,169 | 0.94 | 176,506 | 17,330 | 15.3 | 202 | 11.7 | 8.5 | 1.1 | 0.2 | 36,340 |
| | 200,000–+ | dwt | 294 | 274 | 0.93 | 271,391 | 22,170 | 15.7 | 202 | 12.2 | 11.0 | 1.1 | 0.2 | 10,815 |
| Chemical tanker | 0–4,999 | dwt | 1,502 | 893 | 0.59 | 2,158 | 1,387 | 11.9 | 159 | 9.8 | 0.8 | 0.5 | 0.6 | 5,479 |
| | 5,000–9,999 | dwt | 922 | 863 | 0.94 | 7,497 | 3,292 | 13.4 | 169 | 10.6 | 1.6 | 0.6 | 0.4 | 7,199 |
| | 10,000–19,999 | dwt | 1,039 | 1,004 | 0.97 | 15,278 | 5,260 | 14.1 | 181 | 11.7 | 3.0 | 0.6 | 0.4 | 12,318 |
| | 20,000–+ | dwt | 1,472 | 1,419 | 0.96 | 42,605 | 9,297 | 15.0 | 183 | 12.3 | 5.0 | 1.4 | 0.4 | 30,027 |
| Container | 0–999 | TEU | 1,126 | 986 | 0.88 | 8,634 | 5,978 | 16.5 | 190 | 12.4 | 2.8 | 0.9 | 0.2 | 12,966 |
| | 1,000–1,999 | TEU | 1,306 | 1,275 | 0.98 | 20,436 | 12,578 | 19.5 | 200 | 13.9 | 5.2 | 2.2 | 0.4 | 31,015 |
| | 2,000–2,999 | TEU | 715 | 689 | 0.96 | 36,735 | 22,253 | 22.2 | 208 | 15.0 | 8.0 | 3.1 | 0.5 | 25,084 |
| | 3,000–4,999 | TEU | 968 | 923 | 0.95 | 54,160 | 36,549 | 24.1 | 236 | 16.1 | 13.9 | 3.9 | 0.6 | 53,737 |
| | 5,000–7,999 | TEU | 575 | 552 | 0.96 | 75,036 | 54,838 | 25.1 | 246 | 16.3 | 19.5 | 4.1 | 0.6 | 42,960 |
| | 8,000–11,999 | TEU | 331 | 325 | 0.98 | 108,650 | 67,676 | 25.5 | 256 | 16.3 | 24.4 | 4.5 | 0.7 | 30,052 |
| | 12,000–14,500 | TEU | 103 | 98 | 0.95 | 176,783 | 83,609 | 28.9 | 241 | 16.1 | 23.7 | 4.9 | 0.8 | 8,775 |
| | 14,500–+ | TEU | 8 | 7 | 0.88 | 158,038 | 80,697 | 25.0 | 251 | 14.8 | 25.3 | 6.1 | 1.1 | 806 |
| General cargo | 0–4,999 | dwt | 11,620 | 5,163 | 0.44 | 1,925 | 1,119 | 11.6 | 161 | 8.7 | 0.5 | 0.1 | 0.0 | 23,606 |
| | 5,000–9,999 | dwt | 2,894 | 2,491 | 0.86 | 7,339 | 3,320 | 13.6 | 166 | 10.1 | 1.4 | 0.4 | 0.1 | 16,949 |
| | 10,000–+ | dwt | 1,972 | 1,779 | 0.90 | 22,472 | 7,418 | 15.8 | 174 | 12.0 | 3.4 | 1.2 | 0.1 | 27,601 |
| Liquefied gas tanker | 0–49,999 | cbm | 1,104 | 923 | 0.84 | 6,676 | 3,815 | 14.2 | 180 | 11.9 | 2.4 | 0.6 | 0.4 | 11,271 |
| | 50,000–199,999 | cbm | 463 | 444 | 0.96 | 68,463 | 22,600 | 18.5 | 254 | 14.9 | 17.9 | 4.1 | 0.6 | 29,283 |
| | 200,000–+ | cbm | 45 | 43 | 0.96 | 121,285 | 37,358 | 19.3 | 277 | 16.9 | 33.5 | 4.0 | 1.0 | 5,406 |

**Figure 5-1 Emission specifics by ship type and size for 2012, part 1 (Source: IMO 2015)**

**Table 5-1 Capacity utilization of sea transport for different types of ships (ifeu et al. 2016, p. 32)**

| Vessel types | Trade lane / size class | Capacity utilization factor |
|---|---|---|
| **BC (dry, liquid and GC)** | Suez trade | 49% |
| | Transatlantic trade | 55% |
| | Transpacific trade | 53% |
| | Panama trade | 55% |
| | Other global trade | 56% |
| | Intra-continental trade | 57% |
| | Great lake | 58% |
| **Bulk carrier dry** | Feeder (5 000 - 15 000 dwt) | 60% |
| | Handysize (15 000 - 35 000 dwt) | 56% |
| | Handymax (35 000 - 60 000 dwt) | 55% |
| | Panamax (60 000 - 80 000 dwt) | 55% |
| | Aframax (80 000 - 120 000 dwt) | 55% |
| | Suezmax (120 000 - 200 000 dwt) | 50% |
| **Bulk carrier liquid** | Feeder (5 000 - 15 000 dwt) | 52% |
| | Handysize (15 000 - 35 000 dwt) | 61% |
| | Handymax (35 000 - 60 000 dwt) | 59% |
| | Panamax (60 000 - 80 000 dwt) | 53% |
| | Aframax (80 000 - 120 000 dwt) | 49% |
| | Suezmax (120 000 - 200 000 dwt) | 48% |
| | VLOC(+) (>200 000 dwt) | 48% |
| **General cargo (GC)** | All trades, all size classes | 60% |
| **Container vessel (CC)** | All trades, all size classes | 70% |
| **Ferry / RoRo vessels** | All trades, all size classes | 70% |

Note: BC = bulk carrier, GC = general cargo, CC = container cargo vessel.

| Ship type | Size category | Units | Number active | | Decimal AIS coverage of in-service ships | Avg. dead-weight (tonnes) | Avg. installed power (kW) | Avg. design speed (knots) | Avg. days at sea | Avg.* sea speed (knots) | Avg.* consumption ('000 tonnes) | | | Total $CO_2$ emissions ('000 tonnes) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | IHSF | AIS | | | | | | | Main | Auxiliary | Boiler | |
| Oil tanker | 0–4,999 | dwt | 3,500 | 1,498 | 0.43 | 1,985 | 1,274 | 11.5 | 144 | 8.7 | 0.6 | 0.6 | 0.2 | 14,991 |
| | 5,000–9,999 | dwt | 664 | 577 | 0.87 | 6,777 | 2,846 | 12.6 | 147 | 9.1 | 1.1 | 1.0 | 0.3 | 4,630 |
| | 10,000–19,999 | dwt | 190 | 171 | 0.90 | 15,129 | 4,631 | 13.4 | 149 | 9.6 | 1.6 | 1.7 | 0.4 | 2,121 |
| | 20,000–59,999 | dwt | 659 | 624 | 0.95 | 43,763 | 8,625 | 14.8 | 164 | 11.7 | 3.7 | 2.0 | 0.6 | 12,627 |
| | 60,000–79,999 | dwt | 391 | 381 | 0.97 | 72,901 | 12,102 | 15.1 | 183 | 12.2 | 5.8 | 1.9 | 0.6 | 9,950 |
| | 80,000–119,999 | dwt | 917 | 890 | 0.97 | 109,259 | 13,813 | 15.3 | 186 | 11.6 | 5.9 | 2.6 | 0.8 | 25,769 |
| | 120,000–199,999 | dwt | 473 | 447 | 0.95 | 162,348 | 18,796 | 16.0 | 206 | 11.7 | 8.0 | 3.1 | 1.0 | 17,230 |
| | 200,000–+ | dwt | 601 | 577 | 0.96 | 313,396 | 27,685 | 16.0 | 233 | 12.5 | 15.3 | 3.6 | 1.1 | 36,296 |
| Other liquids tankers | 0–+ | dwt | 149 | 39 | 0.26 | 670 | 558 | 9.8 | 116 | 8.3 | 0.3 | 1.3 | 0.5 | 5,550 |
| Ferry – pax only | 0–1,999 | gt | 3,081 | 1,145 | 0.37 | 135 | 1,885 | 22.7 | 182 | 13.9 | 0.8 | 0.4 | 0.0 | 10,968 |
| | 2,000–+ | gt | 71 | 52 | 0.73 | 1,681 | 6,594 | 16.6 | 215 | 12.8 | 3.9 | 1.0 | 0.0 | 1,074 |
| Cruise | 0–1,999 | gt | 198 | 75 | 0.38 | 137 | 914 | 12.4 | 102 | 8.8 | 0.3 | 1.0 | 0.5 | 1,105 |
| | 2,000–9,999 | gt | 69 | 53 | 0.77 | 1,192 | 4,552 | 16.0 | 161 | 9.9 | 1.3 | 1.1 | 0.4 | 580 |
| | 10,000–59,999 | gt | 115 | 108 | 0.94 | 4,408 | 19,657 | 19.9 | 217 | 13.8 | 9.1 | 9.2 | 1.4 | 6,929 |
| | 60,000–99,999 | gt | 87 | 85 | 0.98 | 8,425 | 53,293 | 22.2 | 267 | 15.7 | 30.8 | 26.2 | 0.6 | 15,415 |
| | 100,000–+ | gt | 51 | 51 | 1.00 | 11,711 | 76,117 | 22.7 | 261 | 16.4 | 47.2 | 25.5 | 0.5 | 10,906 |
| Ferry – ro-pax | 0–1,999 | gt | 1,669 | 732 | 0.44 | 401 | 1,508 | 13.0 | 184 | 8.4 | 0.6 | 0.2 | 0.0 | 4,308 |
| | 2,000–+ | gt | 1,198 | 1,046 | 0.87 | 3,221 | 15,491 | 21.6 | 198 | 13.9 | 6.0 | 1.4 | 0.0 | 26,753 |
| Refrigerated bulk | 0–1,999 | dwt | 1,090 | 763 | 0.70 | 5,695 | 5,029 | 16.8 | 173 | 13.4 | 3.0 | 2.3 | 0.4 | 17,945 |
| Ro-ro | 0–4,999 | dwt | 1,330 | 513 | 0.39 | 1,031 | 1,482 | 10.7 | 146 | 8.8 | 1.1 | 2.5 | 0.3 | 15,948 |
| | 5,000–+ | dwt | 415 | 396 | 0.95 | 11,576 | 12,602 | 18.6 | 209 | 14.2 | 6.8 | 3.6 | 0.4 | 13,446 |
| Vehicle | 0–3,999 | vehicle | 279 | 261 | 0.94 | 9,052 | 9,084 | 18.3 | 222 | 14.2 | 5.4 | 1.6 | 0.3 | 6,200 |
| | 4,000–+ | vehicle | 558 | 515 | 0.92 | 19,721 | 14,216 | 20.1 | 269 | 15.5 | 9.0 | 1.4 | 0.2 | 18,302 |
| Yacht | 0–+ | gt | 1,750 | 1,110 | 0.63 | 171 | 2,846 | 16.5 | 66 | 10.7 | 0.4 | 0.5 | 0.0 | 3,482 |
| Service – tug | 0–+ | gt | 14,641 | 5,043 | 0.34 | 119 | 2,313 | 11.8 | 100 | 6.7 | 0.4 | 0.1 | 0.0 | 21,301 |

**Figure 5-2 Emission specifics by ship type and size for 2012, part 2 (Source: IMO 2015)**

| Ship type | Size category | Units | Number active | | Decimal AIS coverage of in-service ships | Avg. dead-weight (tonnes) | Avg. installed power (kW) | Avg. design speed (knots) | Avg. days at sea | Avg.* sea speed (knots) | Avg.* consumption ('000 tonnes) | | | Total $CO_2$ emissions ('000 tonnes) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | IHSF | AIS | | | | | | | Main | Auxiliary | Boiler | |
| Miscellaneous – fishing | 0–+ | gt | 22,130 | 4,510 | 0.20 | 181 | 956 | 11.5 | 164 | 7.4 | 0.4 | 0.4 | 0.0 | 50,959 |
| Offshore | 0–+ | gt | 6,480 | 5,082 | 0.78 | 1,716 | 4,711 | 13.8 | 106 | 8.0 | 0.7 | 0.6 | 0.0 | 27,397 |
| Service – other | 0–+ | gt | 3,423 | 2,816 | 0.82 | 2,319 | 3,177 | 12.8 | 116 | 7.9 | 0.7 | 0.4 | 0.0 | 11,988 |
| Miscellaneous – other | 0–+ | gt | 3,008 | 64 | 0.02 | 59 | 2,003 | 12.7 | 117 | 7.3 | 0.4 | 0.4 | 0.0 | 7,425 |

* indicates the use of weighted averaging (weighted by days at sea for each individual ship).

**Figure 5-3 Emission specifics by ship type and size for 2012, part 3 (Source: IMO 2015)**

| Lengteklasse | Aandeel bezoeken | Representatief scheepstype | Energiegebruik (kWh/km) |
|---|---|---|---|
| Klein (<86m) | 33% | R.H.K. (Rijn-Herne-Kanaal) schip (96 TEU) (M6) | 29 |
| Middel (86-110m) | 44% | Groot Rijnschip (208 TEU) (M8) | 38 |
| Groot (>110m) | 20% | Verleng groot Rijnschip (272 TEU) (M9) | 46 |
| Duwboot | 2% | - | - |

**Figure 5-4 Energy demand in kWh/km for inland vessels by length (Source: den Boer et al. 2017)**

| Marine sector | Fuel type | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|---|
| International shipping | HFO | 542.1 | 551.2 | 516.6 | 557.1 | 554.0 |
| | MDO | 83.4 | 72.8 | 79.8 | 90.4 | 94.9 |
| | LNG | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **Top-down international total** | **All** | **625.5** | **624.0** | **596.4** | **647.5** | **648.9** |
| Domestic navigation | HFO | 62.0 | 44.2 | 47.6 | 44.5 | 39.5 |
| | MDO | 72.8 | 76.6 | 75.7 | 82.4 | 87.8 |
| | LNG | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 |
| **Top-down domestic total** | **All** | **134.9** | **121.0** | **123.4** | **127.1** | **127.6** |
| Fishing | HFO | 3.4 | 3.4 | 3.1 | 2.5 | 2.5 |
| | MDO | 17.3 | 15.7 | 16.0 | 16.7 | 16.4 |
| | LNG | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| **Top-down fishing total** | **All** | **20.8** | **19.2** | **19.3** | **19.2** | **19.0** |
| **All fuels top-down** | | **781.2** | **764.1** | **739.1** | **793.8** | **795.4** |

| Marine sector | Fuel type | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|
| International shipping | HFO | 773.8 | 802.7 | 736.6 | 650.6 | 716.9 | 667.9 |
| | MDO | 97.2 | 102.9 | 104.2 | 102.2 | 109.8 | 105.2 |
| | LNG | 13.9 | 15.4 | 14.2 | 18.6 | 22.8 | 22.6 |
| **Bottom-up international total** | **All** | **884.9** | **920.9** | **855.1** | **771.4** | **849.5** | **795.7** |
| Domestic navigation | HFO | 53.8 | 57.4 | 32.5 | 45.1 | 61.7 | 39.9 |
| | MDO | 142.7 | 138.8 | 80.1 | 88.2 | 98.1 | 91.6 |
| | LNG | 0 | 0 | 0 | 0 | 0 | 0 |
| **Bottom-up domestic total** | **All** | **196.5** | **196.2** | **112.6** | **133.3** | **159.7** | **131.4** |
| Fishing | HFO | 1.6 | 1.5 | 0.9 | 0.8 | 1.4 | 1.1 |
| | MDO | 17.0 | 16.4 | 9.3 | 9.2 | 10.9 | 9.9 |
| | LNG | 0 | 0 | 0 | 0 | 0 | 0 |
| **Bottom-up fishing total** | **All** | **18.6** | **18.0** | **10.2** | **10.0** | **12.3** | **11.0** |
| **All fuels bottom-up** | | **1,100.1** | **1,135.1** | **977.9** | **914.7** | **1,021.6** | **938.1** |

**Figure 5-5 International, domestic and fishing $CO_2$ emissions 2007–2011 (million tons), using top-down and bottom-up method, respectively (Source: IMO 2015)**

**Table 5-2 Regions within the European Short Sea Shipping Area (Source: Eurostat 2017)**

| The following sea regions have been taken into account to group the short sea shipping partner ports: the Baltic, the North Sea, the Atlantic Ocean (including the English Channel and the Irish Sea), the Mediterranean and the Black Sea. |
|---|
| 1. The Baltic: |
| Danish ports below the Helsingborg–Korsør–Nyborg–Kolding line (including Helsingor).<br>All ports of Finland, Estonia, Latvia, Lithuania and Poland as well as German and Russian ports on the Baltic.<br>The Swedish ports on the Baltic from Helsingborg (included). |
| 2. The North Sea: |
| All ports of Norway, the Netherlands and Belgium as well as the ports of Germany on the North Sea.<br>Swedish ports on the North Sea from Helsingborg (excluded).<br>Danish ports on north of the Helsingborg–Korsor–Nyborg–Kolding line and North Denmark (excluding Helsingor). Faroe Islands.<br>United Kingdom: ports on the east coast of Great Britain from Ramsgate (included) to Cape Wrath in Scotland, the Shetland Islands and Orkney Islands. |
| 3. The Atlantic Ocean: |
| United Kingdom: ports of Great Britain on the Channel (from Ramsgate excluded) and the west coast to Cape Wrath in Scotland; ports in Northern Ireland.<br>All ports of Ireland, Portugal (including Açores and Madeira) and Iceland.<br>French ports on the Atlantic Ocean and on the Channel, up to the Belgian border.<br>Spanish ports on the Atlantic Ocean to Tarifa (included); Canary Islands are included. |
| 4. The Mediterranean: |
| Spanish ports on the Mediterranean from Tarifa (excluded).<br>French ports on the Mediterranean.<br>All ports of Malta, Italy, Slovenia, Croatia, Bosnia-Herzegovina, Montenegro, Albania, Greece, Cyprus, Syria, Lebanon, Occupied Palestinian territory, Libya, Tunisia, Algeria and Gibraltar.<br>Ports of Morocco, Egypt and Israel on the Mediterranean.<br>Ports of Turkey on the Mediterranean (including the ports on the Bosporus). |
| 5. The Black Sea: |
| All Black Sea ports excluding the ports on the Bosporus. |
| 6. Others: |
| Non-identified ports of Denmark, Germany, Spain, France, the United Kingdom, Israel, Morocco, Russia, Sweden, Turkey and Egypt; river ports of EU countries. |
| Ports located in Morocco–West Africa, Egypt–Red Sea, Israel–Red Sea and Russia–Barents and White Seas are not part of the European short sea shipping area. |

# 6 References


AIS Marine Traffic (2017): MarineTraffic Voyage planner - Distance calculator - Route finder. http://www.marinetraffic.com/en/voyage-planner. Last access: 21 September 2017.

Bialystocki, N.; Konovessis, D. (2016): On the estimation of ship's fuel consumption and speed curve: A statistical approach. Journal of Ocean Engineering and Science 1(2)157–166. doi: 10.1016/j.joes.2016.02.001.

den Boer, E.; Meerwaldt, H.; van Grinsven, A. (2017): Carbon footprint containerlogistiek haven van Rotterdam 2015. Goederenvervoer / Havens / Containers / Logistiek / Kooldioxide/ VT:Footprint No. 17.4j21.05. Delft: Havenbedrijf Rotterdam.

Davis, J. (2016): sea distance calculator. http://www.marinevesseltraffic.com/2013/07/distance-calculator.html. Last access: 21 September 2017.

Ecoinvent (2012b): transport, freight, sea, transoceanic ship - GLO (Global). dataset. Ecoinvent 3.3 dataset documentation. Ecoinvent Centre. https://v33.ecoquery.ecoinvent.org/Details/UPR/49152DDE-B135-4212-894E-1E604CE01A74/8B738EA0-F89E-4627-8679-433616064E82

Ecoinvent (2012a): transport, freight, sea, transoceanic tanker - GLO (Global). dataset. Ecoinvent 3.3 dataset documentation. Ecoinvent Centre. https://v33.ecoquery.ecoinvent.org/Details/UPR/7857501F-66F5-4C54-BB80-AD5B38F4B339/8B738EA0-F89E-4627-8679-433616064E82

Eurostat (2017): Maritime transport statistics - short sea shipping of goods. eurostat. Statistics Explained. http://ec.europa.eu/eurostat/statistics-explained/index.php/Maritime_transport_statistics_-_short_sea_shipping_of_goods#Short_sea_shipping_by_sea_region_and_country. Last access: 06 September 2017.

ICCT (2016): European Vehicle Market Statistics. Pocketbook 2015/16. European Vehicle Market Statistics. The International Council on Clean Transportation. http://www.theicct.org/sites/default/files/publications/ICCT_EU-pocketbook_2015.pdf. Last access: 08 August 2017.

ifeu; INFRAS; IVE (2016): Ecological Transport Information Tool for Worldwide Transports. Methodology and Data Update. Methodology and Data Update. Berne, Hannover, Heidelberg: IVE (Ingenieurgesellschaft für Verkehrswesen mbH, Hannover), Infras (Consulting, Analysis and Research), ifeu (Institut für Energie- und Umweltforschung Heidelberg GmbH), for EcoTransIT World Initiative. http://ecotransit.org/download/ETW_Methodology_Background_Report_2016.pdf. Last access: 05 Dezember 2017.

IMO (2015): Third IMO GHG Study 2014. No. Executive Summary and Final Report. The International Maritime Organization.

Lu, R.; Turan, O.; Boulougouris, E. (2013): Voyage optimisation: prediction of ship specific fuel consumption for energy efficient shipping. Low Carbon Shipping Conference (Bd. 44). http://www.lowcarbonshipping.co.uk/files/ucl_admin/LCS%202013/Lu_et_al.pdf. Last access: 16 Oktober 2017.

Marin (2016): Sea shipping emissions 2014: Netherlands continental shelf, 12-mile zone, port areas and Ospar region II. Final Report No. 28771-1-MSCN-rev.2. Wageningen: MARIN, for RIVM/Emissieregistratie and Port of Rotterdam.

Schmied, M.; Knörr, W. (2013): Berechnung von Treibhausgasemissionen in Spedition und Logistik gemäß DIN EN 16258. Leitfaden No. 2. aktualisierte Auflage. Begriffe, Methoden, Beispiele. DSLV Deutscher Speditions- und Logistikverband e.V.